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Analysis of the Accidental Explosion at Pepcon, Henderson, Nevada, May 4, 1988

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ANALYSIS OF THE ACCIDENTAL EXPLOSION AT PEPCON, HENDERSON, NEVADA, MAY 4, 1988

by

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ABSTRACT

Several hours of fire and numerous explosions destroyed the Pacific Engineering Company plant in Henderson, Nevada, that manufactured ammonium perchlorate (AP) for rocket fuel. This incident began about 1130 PDT on May 4, 1988, with a fire in their Batch House that grew out of control and caused a first large explosion at about 1153 PDT. The final and largest explosion occurred about 1157 PDT. Damages to the surrounding community were surveyed and interpreted as airblast overpressures versus distances, which allowed an estimate of 1-kiloton nuclear free-air-burst for the equivalent explosion yield. This could be reproduced by 250-tons TNT burst on the ground surface.

Weather reports were obtained from the National Weather Services which indicated somewhat enhanced airblast propagation downwind toward northerly directions and attenuated airblast propagations upwind in southerly directions. It was impossible, for lack of winds aloft information below about 500 m above ground, to determine whether there was any atmospheric acoustic airblast focusing.

Several seismic recordings in Las Vegas showed the greatest ground motion resulted from the airblast wave passage, traveling at near acoustic speed. Ground wave arrival times were not sufficiently precise to allow seismic speed interpretations.

Of the 4000 tons of AP apparently stored in and around the plant, it appears that about 1500 tons detonated in the largest explosion. This leads to a conclusion that the TNT airblast equivalence factor for AP is near 1/6. An independent estimate, based on analysis of more ideal close-in structural deformations, suggested an equivalence factor of 1/3.

ACKNOWLEDGMENTS

Particular appreciation is expressed to Jim McDonald and Penny Vann, of Texas Tech University, who managed to rush to the accident scene and assist with off-site damage assessment, before clean-up and repair activities could obscure many of the interesting effects. Their copious notes, records, and photos should, with time and their academic diligence, provide for significant refinement of the hurried analyses here reported.

Joe Woodruff, of URS/John A. Blume & Associates, DOE-NVO consultants, provided copies of and interpretation instructions for the seismic records which have been used. They have allowed close estimates of times for the two largest explosions as well as a relative yield estimate for the smaller event.

Weather reports were obtained from the NOAA National Weather Services forecast office at McCarran Field, Las Vegas International Airport.

Claude Merrill and John Marshall, of the USAF Rocket Propulsion Laboratory at Edwards AFB, CA, provided the early material quantities, which encouraged the evaluation of TNT explosives equivalence that had previously been largely misunderstood.

Friendly and helpful cooperation was shown by almost all of the Nevada residents whom we encountered, particularly when we explained our investigative purposes. We met with no hostility; rather there was a general desire to clean up the mess and conduct a competent assessment of their problems.

Finally, discussions with several other Sandians have been most valuable in the preparation and review of this report. Particularly helpful have been Carter Broyles, John Banister, Hugh Church, Nancy Finley, Fred Norwood, Paul Cooper, and Ronald Bentley.

ANALYSIS OF THE ACCIDENTAL EXPLOSION AT PEPCON, HENDERSON, NEVADA, MAY 4, 1988

INTRODUCTION

A series of large explosions destroyed the Pacific Engineering Company plant (PEPCON) in Henderson, Nevada, which manufactures ammonium perchlorate (AP) for rocket fuel, beginning about 1151 PDT (1851 UT, Universal Time) on May 4, 1988. First word of this event reached C. D. Broyles, Sandia National Laboratories Director of Field Engineering (SNLA-7100), within an hour when B. G. West (SNLA-7135), support representative at the Las Vegas airport, McCarran Field, reported blast damage at the terminal. Concern for a number of Sandians who work at Mercury and Tonopah - and their families - who live near the explosion initiated this investigation.

The Air Force Range Safety Office, Patrick Air Force Base, Florida, supports rapid-response investigations of explosion damage by the Glass Research & Testing Laboratory (GRTL), Texas Tech University (TTU), in Lubbock, Texas. This program aims to improve damage, hazard, and injury prediction for potential accidental detonations of large missiles. They were promptly contacted and agreed to cooperate in a survey of the Henderson explosion. The author arrived in Las Vegas by 1800 PDT, while the TTU team of J. R. McDonald and W. P. Vann was able to get there near midnight following the blast.

BACKGROUND

History

Sandia involvement in explosion airblast phenomenology began with weapons effects research and field test participation in atmospheric nuclear tests during the 1950s. Study of "anomalous" blast propagation, peculiarly strong waves at weather-dependent long distances, began after a number of windows were smashed in Las Vegas, 66 miles (107 km) from one of the first nuclear explosion tests conducted in Frenchman Flat [*Cox et al.*, 1954] in 1951, in what is now the Department of Energy (DOE) Nevada Test Site, operated by the Nevada Operations Office (NVO). The science has progressed to a point where it is now usually possible to predict such occurrences, and to avoid explosion testing when weather conditions threaten to cause serious nuisance or hazardous damage to neighboring communities. A few prediction failures, however, have demonstrated unpredictability in some critical elements of small-scale wind circulations.

Airblast Predictions

Airblast prediction for test explosions, as outlined by *ANSI Standard S2.20* [1983], begins with a statement of the explosion yield, location, and burst environment, either on the ground, above ground, or underground or underwater. All of this needed information is not usually acquired for accidental detonations. Hydrocode calculations [*Needham et al.*, 1975, 1981] provide explosion characteristics of airblast overpressure, pressure-time waveform signature, and other parameters, versus distance for a reference explosion yield burst in a calm *U. S. Standard Atmosphere* [*NASA et al.,* 1962] at sea level pressure and away from any reflecting surfaces. The usually referenced Standard 1-kiloton nuclear explosion (1-kt NE) is not an SI-metric unit, but it has been accepted and defined [*ASTM,* 1974] as an energy release of 4.2×10^{12} J. This airblast could be duplicated by a 250-t HE (chemical high explosive) surface burst (hemispherical), by assuming 0.5 for NE-to-HE equivalence, since about half the energy release from a nuclear explosion goes out in radiation that does not contribute to shock wave formation. Also, the normally referenced HE is TNT, so these two abbreviations are synonymous. Similarity scaling laws allow translation of these parameters into values for other specified yields, explosives, or environments [*Glasstone and Dolan*, 1977].

Refraction calculations can be made to show how the atmospheric acoustic lens can distort airblast propagation [*Cox,* 1958], depending on upper air winds and temperatures, to either amplify or attenuate Standard overpressures derived for radially expanding airblast waves [*Reed,* 1980b]. Given a description of upper air conditions, it is thus possible to make an overpressure prediction for each point around an explosion test site.

It is practically impossible, even with Cray computers, to calculate the response of and possible damage to every structure or structural element from its expected overpressure exposure. Windowpanes are particularly sensitive to breakage by airblast waves [*PPG, c.*1961], but they come in a variety of sizes and shapes, a small number of thicknesses, a continuum of exposure directions to a blast, and an infinity of reflecting, shadowing, and diffracting environments. Furthermore, glass itself demonstrates notoriously non-repetitive breaking behavior [*Ansevin,* 1964], in spite of apparent, visible uniformity. Failure strength for a particular pane depends on its distribution of surface microflaws (from manufacture, handling, sandstorms, wetting, air pollution, and other factors) which are necessary for crack initiation [*Kanabolo and Norville,* 1985]. Consequently, blast damage prediction is forced to rely on empirical statistical extrapolation from those few incidents, usually accidents, where explosion source strength and weather conditions were sufficiently known to allow overpressure estimates that could be correlated with breakage.

Accident Analysis

Accident analysis requires reversing this normal airblast prediction sequence. From consideration of damages to windows and other materials, a seasoned guess must be made of the overpressure that caused it. From the separation distance to the explosion, and considering possible weather influences in that direction of propagation, a Standard explosion overpressure-distance curve can be constructed through the data point. By comparison with a 1-kt NE curve, scaling laws allow estimating a source explosion yield. Iteration over a number of damage observations improves confidence in the result.

METHODOLOGY

Las Vegas Weather, May 4, 1988

Surface weather reports are recorded at McCarran Field by NOAA National Weather Services observers a few minutes before each hour (plus special reports when significant changes occur). At 1047 PST (1147 PDT) they reported broken clouds at 15,000 ft, overcast cirrus clouds at 25,000 ft above the surface, visibility 50 miles, sea level extrapolated pressure 1008.8 mb (millibars), temperature 75°F, dew point 24°F, wind blowing from 180° (south) at 14 knots with gusts to 26 knots, and altimeter setting 29.84" Hg. Ambient pressure at 1900 ft above mean sea level (586 m MSL), near the explosion elevation, was approximately 941 mb or 94.1 kPa.

Unfortunately, upper air observations for the region are only made at Desert Rock, near Mercury and over 100 km northwest of Las Vegas. They are made with balloon-borne radiosondes, synonymously called rawinsondes, rawins, or raobs. Ascensions are made at world-wide synoptic times, 0000 UT and 1200 UT, daily. Desert Rock is near 1048 m MSL, so that airblast propagation conditions at 1851 UT around Henderson must be estimated from combined data sources. Observed weather conditions at altitudes are shown in Tables 1 to 3, for 1200 UT May 4, 0000 UT May 5, and 1200 UT May 5, 1988. Table 4 shows interpolated values above the Las Vegas surface observation for the time of the explosions. Temperatures from morning and evening soundings and interpolated values are graphed in Figure 1. Temperature decreased rapidly with height above the surface, with a nearly adiabatic (neutral stability) lapse rate, as expected with strong, turbulent, southerly winds. Wind speeds increased with height from 7.2 m/s (14 knots) at the surface to 16.5 m/s (32 knots) at 3084 m (10 kft) MSL. That upper level value provides a rule-of-thumb estimate for peak surface wind gust speeds, which were reported at 26 knots (13.4 m/s).

Sound Velocity

Sound speed depends on temperature, and directed sound velocity equals sound speed plus a directed wind component [*Cox et al.*, 1954]. Sound velocity versus altitude curves for various directions are shown in Figures 2 and 3, based on estimated shot-time conditions. When sound velocity decreases with altitude (*e.g.*, 150° direction in Figure 2), sound or blast rays are refracted upward away from ground to cause attenuated airblast at ground level in that azimuthal direction. When sound velocity increases with altitude (330° in Figure 2) airblast will be refracted toward ground, enhancing overpressures above Standard propagation. When sound velocity decreases, then increases with altitude the wave may be folded to form a caustic or focus with greatly amplified overpressures in a small area. Lacking actual weather observations between Las Vegas and Desert Rock elevations, it is not possible to determine whether any focusing structure was present. Prevailing southerly winds should have caused generally enhanced northward propagations while attenuating southward propagations, because wind speed normally increases with height above the ground-friction surface.

Standard Explosion Overpressures

The ANSI or AFWL Standard 1-kt-NE explosion overpressure versus distance curve is shown in Figure 4, along with some typical weather-influenced curves, adjusted for 94.1-kPa ambient pressure at 579-m MSL altitude. A curve for 2-kt NE is also provided for estimating the effect of cube-root-of-yield scaling. Sound velocity increase with height in a simple inversion, or decrease with height in a simple gradient, gives the fan of curves with displacements from Standard that are dependent upon the strength of the inversion or gradient [*Reed*, 1980b]. The top curve is an envelope which contains about 90% of focused overpressure observations [*Reed*, 1969]. Even that boundary has been exceeded in several extreme cases, with the "world record" observation of 9.6-X overpressure magnification in a French sonic boom test [*Wanner et al.*, 1972].

Glass Breakage

A lognormal probability distribution curve [*Aitchison and Brown*, 1969], a special case of the Weibull distribution commonly found applicable to strength of materials problems [*Weibull*, 1951], for glass pane breakage versus incident overpressure is shown in Figure 5. The mean curve connects data at high overpressures (1-5 psi, 7-35 kPa) from Civil Defense housing experiments at large nuclear and HE tests [*Wilton and Gabrielsen*, 1973] with data at low overpressures (200 to 400 Pa) from an accidental explosion at Medina Facility, San Antonio, Texas, in 1963 [*Reed et al.*, 1968]. That one accident involved meticulously inventoried, classified explosives to provide a source yield, and

a nearby special Weather Bureau radiosonde observation was launched in accord with Civil Defense disaster plans. Two recent, point validations of this curve are shown, results from 1- and 8-kt NE equivalent explosions of ammonium nitrate-fuel oil slurry (ANFO), at White Sands Missile Range, New Mexico [*Reed and Church,* 1984, 1986].

Medina results were also categorized by windowpane area in Figure 5 for small casement windows, typical double-hung windows, large picture windows, and very large store windows. An expression for the mean breaking load, b, for square plates is

$$b = (K\ f\ H^2 / A) \times \sigma_g^{\pm 1} \tag{1}$$

where f is maximum tension stress, H is plate thickness, A is plate area, and K is a constant [*Ansevin,* 1964]. The geometric standard deviation factor, σ_g, is assumed to include variances from glass strength, atmospheric propagation, randomized azimuthal exposure orientation, as well as pane shape factors which depend on specific length-to-width aspect ratios.

Four pane size categories from the Medina incident [*Reed et al.,* 1968] have been used to calculate overpressures needed to give reported damages in Table 5, assuming: a) response for small A-panes is based on 4-pane casement window units; b) large C- and D-panes were affected by a factor of 2 dynamic amplification [*Daniels and Overbeck,* 1980]; c) single-strength (SS) common glass was used for A- and B-panes; and d) plate glass was used for C- and D-panes. Thickness for D-panes was adjusted to give a good comparative relationship with typical 1/4" (6.4-mm) C-panes. Necessary overpressures were calculated for the total San Antonio experience as well as for a sub-set that was selected with predicted near-uniform overpressure exposures. Arithmetic average overpressures for these two cases were then interpreted in reverse to show an effective "average" pane. Both calculations resulted in average SS panes of near 4-ft^2 (0.38-m^2) area, so that value was adopted as the basis for estimating specific pane responses by comparison with the "average" damage predictor

$$\Delta p = B \times 2.5^{\pm 1} \tag{2}$$

where the mean breaking overpressure, B = 7.5 kPa for 4-ft^2 SS panes. For other panes,

$$B_i = (7.5 \times 0.3804 / 2.056 \times 102.15)\ H_i^2\ f_i / A_i\ D_i\ c_i \tag{3}$$

for f kPa, A m^2, and H mm, where D is dynamic amplification factor and c is the effective number of panes per casement, as shown in Table 6.

To facilitate analysis of field data collections, damage probabilities have been further transformed to provide Figures 6 to 8. In Figure 6, some popular glasses were used to predict breakage for 1-ft^2 (0.095-m^2) panes, with mean breaking loads listed in Table 7. For 100-ft^2 panes simply divide the indicated overpressure by 100. Or, for example, a 4-ft^2 SS pane would have a 5-kPa mean breaking load, so that 1 broken in 10,000, $\sigma_g = -3.71$, would be expected from $5000 \times 2.5^{-3.71} = 167$ Pa, incident airblast overpressure. This result is below the "threshold" of 200 Pa, which would, by inverse calculation, be expected to break 2.25 panes with 10,000 at risk. On the other hand, it can be reasoned that this threshold was determined from incidents with nearby overpressure measurements, eliminating much of the assumed weather variance. Thus, only one pane was broken by measured 200-Pa exposures to about 50,000 and 500,000 panes, respectively, in two incidents.

Figure 7 was constructed by assuming SS glass in 24 panes per house, each 6 ft^2 (0.57 m^2), giving a total window area that is near building code values for moderate-size homes. This assumes larger panes rather than small casement windows so common in San Antonio (and Albuquerque) architecture [*Reed,* 1980a] but not in Las Vegas. Also considered was the fact that only about one-half of the panes in a typical house would be observed during a damage survey from a moving automobile, as calculated in Table 8. The inverse, houses per visible broken pane, is shown in Figure 8, for use where damage is relatively sparse. Some readers may note that these figures differ somewhat from earlier ones in a preliminary letter report on the Henderson incident (J. W. Reed, ltr. to C. D. Broyles, June 16, 1988) in result of refined derivations and calculations.

SURVEY RESULTS

Preliminary Assessment

Residential development has progressed rapidly southward from Las Vegas in recent years, so that current new building projects extend inside the city limits of Henderson. These areas were thus closest to the PEPCON explosions, as shown by a Henderson map in Figure 9, and suffered the most severe housing damage. In Arroyo Grande Estates, at 2-km range, a first inspection, on the evening of May 4, 1988, left an impression of slightly less severe blast effects than were encountered in a 1955 Civil Defense experiment that exposed test housing to 0.5-psi (3.5-kPa) overpressure from an atmospheric nuclear test [*Cox and Reed,* 1957] in Yucca Flats, Nevada. In that event, some casement window glass was blown across a room and partially embedded in the far wall. By contrast, however, there were a few panes that were popped out of their frame as

the casement was bent inward by the blast and even survived landing on the concrete floor. In addition, entry doors were torn from their hinges and locks, and an overhead garage door was demolished and rolled up in a ball.

The Admin Park for DNA Project MISTY PICTURE [*Reed et al.,* 1988], an explosion test at White Sands Missile Range, New Mexico, was exposed to nearly 2.8-kPa (0.4-psi) overpressure. There was incomplete breakage of building windows facing the blast, although some shards were thrown inward several meters, resulting in a facial cut on one participant. An overhead garage door in a hemispherical air bag building was destroyed but not rolled up like the previously cited door. This particular door had survived 1.4 kPa from a similar explosion test, MINOR SCALE [*Reed and Church,* 1986], two years earlier. A TTU glass exposure experiment, across the road from the Admin Park at MISTY PICTURE and slightly closer to the explosion, had witness plates of aluminum foil placed 3 m behind the panes. These only received a few impacts from flying glass shards [*Dillingham,* 1987].

By comparison it appeared that Arroyo Grande Estates had experienced something near these two test conditions, 2.8- to 3.5-kPa overpressure. From Figure 3 this would indicate a source explosion close to the Standard curve for a 1-kt NE spherical free-air burst. This airblast could be duplicated by 250-t HE surface burst. Much later, off-the-record conversations with other accident investigators indicated that close-in damage to relatively ideal structural elements led to a conclusion that 500-t HE seemed a more appropriate equivalent yield. Considering the 26% greater overpressure-distances from a doubled yield and the relatively large scatter of damage interpretations, it is impossible to argue over this factor of 2.

Spot Damage Interpretations

Notes from a two-day survey of damages in Henderson and Las Vegas have been included in Appendix A. Since TTU surveyors reported considerable detail on their tape recorders, only relatively few, seemingly striking or important features were written down by this author. These have been interpreted, through use of Figures 5 through 8, as estimated overpressure-distance values shown in Figure 10. Interpretive details are listed in Tables 9 and 10.

At Arroyo Grande Estates Country Club, one of three large tempered glass windows facing the blast was broken, while the others were knocked down but were not broken, to give the probable overpressure range from 2456 Pa (for 0.5 broken panes) to 5834 Pa (for 1.5 panes). As depicted in Figure 10, this range of values is connected by a solid line with a small solid circle at the geometric mean. The billiard room, also facing the blast, had all three of its large

plate glass panes broken (more than 5/6 of its three panes were broken), indicating over 5600-Pa overpressure. However, there were also three similar but smaller plates which were not broken, leading to an overpressure estimate of less than 2000 Pa. This apparent discrepancy can only be explained as the effect of tiny sample size. Similar evaluation gave a 1900-Pa to 6700-Pa range from one of two windows broken in an interior club office, indicating little attenuation of the blast which blew through the blast-facing window wall and passed through the lounge. An estimated range of 1300 to 4800 Pa was made from one of two SS panes broken in the kitchen.

Great scatter demonstrated by these observations was typical of glass response results with small numbers of exposed samples, and therefore it was not at all discouraging. Arroyo Grande Estates is near 285° azimuth from PEPCON and about crosswind, where propagation was probably not much distorted by atmospheric refraction, so the Standard propagation curve should apply, particularly at such close range. Results thus reasonably well support the early estimate of a 1-kt NE equivalent source.

A construction office trailer in the Silver Springs housing development, at 2.7-km distance and northwest from Arroyo Grande Estates, had one of four windows broken by the blast, yielding a 2700- to 5900-Pa range estimate. This range of values seems high compared to the Standard curve but not so high in comparison with some other, more distant observations.

East of PEPCON, Henderson residences extend to Albany Way, at 2.9 km where only about one broken window per house appeared to result from around 700-Pa overpressure, shown by a large solid circle in Figure 10. Visibility was limited in this older community, however, with high walls and trees obscuring likely additional damaged panes. Near Crest and Buchanan Streets, at 3.21 km, conversation with a resident disclosed 6 broken of 16 exposed SS panes; all were double-pane insulating windows. This inferred around 2600-Pa overpressure, in closer agreement with the Standard curve.

Along Mountain View Road south of Highland Drive, at 4.2 to 4.7 km from PEPCON, there appeared to be window damage to about every other house. This was interpreted as 500-Pa overpressure, well below the -10 m/s gradient curve yet possibly reasonable for its quartering upwind direction. With the strong upper winds the applicable gradient strength (to yield-scaled heights) was near -20 m/s and well beyond the range of 100-lb HE Cape Canaveral test data [*Reed,* 1980] used to define the fan-shaped family of curves. By 6 km in this same general southeasterly direction, no damaged windows were found to six houses beyond Heather Drive, so the overpressure was probably less than about 330 Pa, and similarly below the defined gradient curves.

In downtown Henderson on the northeast side of Water Street, all shops in one section were boarded up; they appeared to contain 16 broken panes if installed with 1/4" plate glass. This would have required 10-kPa overpressure at 4.4-km range, a seemingly high value for a crosswind east direction. Alternatively, assuming 3/16" annealed plates lowers the required overpressure to 5.8 kPa, and assuming further that only 14 panes were actually broken brings the overpressure down to a more reasonable range of 2.7 to 3.6 kPa. Still, the geometric mean point falls slightly above the caustic envelope, requiring refractive wave focusing.

The new Cattle Baron's Casino, which was only nearing completion at 4.2-km distance east-northeast from PEPCON, had 8 of 12 large windows broken, generally facing the blast. This provided an estimated 2300- to 2700-Pa overpressure, again well above the 1-kt NE curve, nearly to the caustic envelope. Along with the Water Street observations, this possibly indicates focusing near 4.3 km east and northeast, which could be explained by 5 m/s wind component adjustments near 400 m above ground.

At McDonald's on Boulder Highway, US-93, their large front window facing the blast was broken, inferring more than 850-Pa overpressure. None of their 16 smaller panes was broken, however, inferring less than 1420-Pa overpressure. This observation pair contains the Standard curve, so they apparently were missed by any focusing.

J. L. Woodruff, of URS/John A. Blume & Associates, seismic consultants to DOE-NVO, lives near Boulder Highway and Flamingo Road, Las Vegas, about 9 km from the blast according to the Las Vegas map in Figure 11. He reported that about one-third of his neighbors had window damage. This was interpreted as 330-Pa overpressure, near the -10 m/s gradient curve and clearly lacking any strong enhancement in spite of their generally downwind direction. They were probably in the "silent zone" between focused caustic arcs.

On Desert Inn Road, just east of Pecos McLeod Avenue at 12.3 km from the explosion, an empty store had several windows punctured by BB-gun holes. Three of six had been broken by the blast. This would infer 1050- to 1600-Pa overpressure, with dynamic amplification of 2, if they had been undamaged previously, but some lower overpressure because of the holes.

An early radio news program reported that a man had been knocked down by building response to the explosion on the thirtieth floor of the Hilton Hotel, on Paradise Road and north of the Las Vegas Convention Center. DOE-NVO collected damage reports from many large structures in their network for gathering responses to underground nuclear test events. Among these the Hilton reported

windows broken on 14 floors, all concentrated in elevator lobbies and facing the blast. TTU attempted unsuccessfully to get details from their management, and damages had already been repaired by two days following the explosion, but the estimated overpressure range was 738 to 786 Pa, indicating considerable focused enhancement.

A store in a shopping center on the west side of Maryland Parkway, just south of Desert Inn Road, had two of its seven large, annealed plate glass windows broken by the blast. An employee suffered head wounds from the breaking glass, that required suturing. This result probably came from 419- to 610-Pa overpressure at 13.8-km distance. A peculiar footnote to this observation was that their one tempered glass window, a replacement following a previous accident, broke the next day (May 5, 1988) during a severe wind storm. None of the remaining annealed panes was broken, even though tempered glass is generally conceded to be about 4 times as strong as annealed glass. It might be speculated that the tempered plate received some unnoticed weakening damage from the blast, but when such plates are damaged they usually fracture immediately into relatively harmless pebbles. Another shop in the same complex had one of its four windows broken, providing a 288- to 552-Pa estimate. These results only indicate modestly enhanced propagation.

Farther north, however, at 15-km range along Sahara Expressway and east of Maryland Parkway, Bertha's Furniture store had two of its four large plate glass show-windows broken. Considering their orientation, about 55° to the approaching wave front, this damage probably came from between 459- and 852-Pa overpressure. Across a street to the west, Christensen's Jewelry only had one of its six windows broken, inferring an overpressure range between 196 and 408 Pa. To the east on Sahara Boulevard, several other damage incidents were recorded by TTU that will likely confirm focusing and the existence of critical wind patterns that were not observed by weather balloons.

Damage Assessment Summary

In summary of these spot damage interpretations in Figure 10, the cloud of data does generally surround a 1-kt NE Standard curve, reinforcing the initial estimate that the largest PEPCON explosion was about equivalent to 250 tons, possibly 500 tons, of chemical high explosives. But ammonium perchlorate is "not detonable", so there are no federal, state, or OSHA standards for treating and handling it as such, nor TNT equivalences for estimating how much AP actually exploded.

AERIAL PHOTO INTERPRETATIONS

Aerial photography was flown over the PEPCON region by EG&G, instrumentation contractors to DOE-NVO, on May 10, 1988. The expectation was that an explosion crater could be dimensioned as an additional yield estimator. Since there was no clear crater formation comparable to ones observed after point explosion tests, no yield scaling was possible. Their photographs did assist in estimating what happened, however, as well as help clear up some map scaling problems that were encountered in connecting the Henderson map in Figure 9 to the Las Vegas map in Figure 11. A sketch of the PEPCON facility in Figure 12, annotated with help from newspaper stories in Appendix B, shows where the initial fire broke out of control in the Batch House, then spread to the Dryer Building and on to the Chloride Building. It is not clear where the first large explosion occurred. What is obvious from these aerial photographs is that the latest and largest explosion occurred in Storage Yard B, nearly 300 m east of the Batch House.

EXPLOSION SOURCE POTENTIALS

A telephone conversation on June 6, 1988, with Claude Merrill, safety official at the USAF Rocket Propulsion Laboratory, Edwards AFB, CA, also concerned with this incident, provided information that there was a total of nearly 8.5 million pounds (3.85 Gg) of AP at the PEPCON plant, distributed by containers and locations shown in Table 11. Storage Area A, northwest of Storage Area B and east of the Chloride Building, held 1,337,800 lb (607 Mg) of AP. Storage Area B, following assumptions about the distribution of the large bins, had contained 3,054,700 lb (1.385 Gg) of AP. By elimination, Storage Area C, between Storage Area A and the Batch House, contained 4,018,300 lb of (1.822 Gg) of AP.

Merrill also related his impressions from a video-camera recording made on Black Mountain, south of Henderson. It showed the early fire followed by an explosion; much later there was "an airburst immediately followed by a ground burst, like a sonic boom, bang, bang". When an edited tape copy was reviewed at Sandia, these late booms appeared to be separated by slightly less than one second.

He also relayed two estimates of TNT equivalence for AP; one by P. Person (New Mexico Institute of Mining & Technology), of 0.266; and one by Morton-Thiokol of 0.38 based on tests with 22.5" (0.58 m) diameter samples. A thermodynamic calculation (P. W. Cooper, SNLA-7133, pers. comm., 1988) showed a chemical energy equivalence of 0.60. In contributing to recent considerations (J. W. Reed, pers. comm., 1988) of missile fuel plant expansion,

Hercules provided an estimate for TNT equivalence of finished fuel material of 0.10 (D. E. Richardson, Hercules, Inc., pers. comm., 1988), based on studies of damages from a missile silo accident. With such a range of competent opinions available, plus the general and official belief that AP is not (at least easily) detonable, determination of the PEPCON explosion source characteristics appeared to take on considerable importance.

A second blast followed by the third and largest blast fit the pattern shown by another video-camera operated at a gravel plant north of PEPCON, and shown on Las Vegas TV Wednesday night (May 4, 1988). The big one came to the left (east) of the second, in agreement with its location at Storage Area B. It is not clear whether this second explosion was in Storage Area A or Storage Area C. Also, where was the first explosion?

The color photograph that was traced for Figure 12 showed light-colored regions in Area B, in Area C, and in a small area south of the Batch House, where one newspaper account indicated a small storage of AP barrels. Area A, however, showed a nearly circular cleared area but it had a somewhat darkened color while the perimeter was blackened. It thus did not appear to have had so ferocious a detonation as the others. TV also showed the second explosion cloud to be much darker than the larger cloud which subsequently lifted from the big explosion. In Area C, a light color pattern showed in parallel bands, each roughly 50-m long, later determined to be mostly melted AP. This area does not indicate any single coherent explosion. It may show results from many small explosions which were reported by plant workers, who miraculously had time to flee with only relatively minor injuries.

Although it is not important to analysis of damage, overwhelmingly caused by the largest explosion, it might appear that the first explosion occurred at the Batch House and a small adjacent storage area. The east end of the Batch House appears to have been blown away. The second, dark explosion could have been a relatively low-order detonation of the 607-Mg AP in Storage Area A.

SEISMIC RECORDS

A number of seismic accelerometer stations have been installed and operated for several years at various places in Las Vegas, particularly in high-rise hotels and office buildings, by DOE-NVO, to document effects from underground nuclear explosion tests at NTS. Stations, numbered 1 through 8 in Table 12, are operated at locations shown in Figures 9 and 11. Some of these are set up to begin recording on receiving a signal above some predetermined noise threshold value.

Continuous recordings are made at Station S-2, at the University of Nevada Las Vegas (UNLV) Chemistry Building, off Maryland Parkway and south of Flamingo Road, and at the Las Vegas water pumping plant, S-8, north of Charleston Avenue in northwest Las Vegas, as shown in Figure 11. It had been hoped that these recordings could be used to determine times for the various reported explosions, but it appears that only the first and third explosion were strong enough to cause a readable oscillation. Some recorders were not even triggered to operate by ground motion arriving from the first explosion wave, and only recorded the airblast wave. Clear audibility of only two blasts was also reported (R. C. Bass, SNLA-7111, pers. comm., 1988) from a point on Sahara Boulevard, between Paradise Road and Maryland Parkway. On the other hand, as previously cited, a video-camera recording gave both video and audio indications of a moderately large explosion about one second before the final, large blast.

The strongest vertical motion seismic signals went off-scale at the playback sensitivity shown. From the tangential accelerometer at S-2, the amplitude ratio appears to be about 7:5. The radial record at S-8 shows a ratio near 16:10, not significantly different. If cube root scaling were assumed to be operative, the yield ratio between these two explosions would be about 3.4:1, and the first explosion near 75-t HE equivalence.

Wave arrival times in Table 12 were used with map-scaled distances to estimate airblast velocities between S-1 and other stations. There was relatively little scatter (< 2 m/s) in these results and no apparent large bias away from the weather report value. This indicated uniform velocity across the city. Consequently, a mean velocity was calculated for each of the two large blasts, as shown in Table 13, since they were found to differ by 0.65 m/s, attributable to normal wind gustiness. Station distances were then adjusted to give uniform wave velocities with yield-dependent pre-acoustic arrivals (positive phase durations) and an RMS best estimate for shot point distance separation, for six station pairs. Only S-8 required more than 100 m adjustment, as shown in Table 12, and commensurate with map reading accuracy on available commercial street maps. Actual shot-times were also determined from these mean value calculations, as well as arrival prediction errors.

Shot-times and distances were then used with ground wave arrival times to calculate ground wave velocities, also shown in Table 12. Various attempts failed to rationalize these erratic results. Although a considerable variation in seismic velocities might be expected for the complex geological structure underlying Las Vegas, arrivals at the closest and farthest stations came unreasonably early. A conclusion was drawn that recorder time bases were not synchronized adequately for such sensitive interpretations. Ground wave arrival time errors in Table 12 were simply calculated from an assumption that the velocity was uniformly 6000 m/s.

Recorded seismic amplitudes are listed in Table 14. S-1 and S-6 were equipped with vertical accelerometers, and gave indicated peak accelerations for first vertical motion. S-2 was equipped with a vertical velocity sensor. Note that S-1 recorded a small wave signal about 80 s prior to the final large wave arrival. This signal was not detected by any other seismometer. Acceleration peaks, a, were translated to vertical velocities, v, with

$$v = a / 2 \pi f \tag{4}$$

assuming a sinusoidal acceleration waveform with frequency, f, based on a wavelength 4 times the rise time of the first acceleration. Airblast overpressure, Δp, required to cause these vertical velocities was obtained from the air-to-ground coupling relationship that

$$\Delta p = \rho c v \tag{5}$$

where airblast sound speed, c, in Table 13 was used with ground density, ρ, assumed to be 1600 kg/m^3. Resultant overpressures were also plotted in Figure 10, for comparison with other information.

Points for Stations S-2 and S-6 fall in the ballpark of the Standard curve and window damage assessments. Results from S-1 appear too high by about a factor of 2, but they could be adjusted by some combination of (a) assuming a lower local ground density, (b) assuming a calibration error in measurement, and (c) adopting a shorter wavelength defined by the first two acceleration peaks rather than by the initial rise time. High frequency oscillation on the S-1 record was not duplicated at any other station. Also, initial, large positive vertical velocities recorded at S-2 were not encountered in other records. Nevertheless, a flow modelling calculation (F. R. Norwood, SNLA-1533, pers. comm., 1988) indicates that such a "bow wave" could be generated in the ground under the postulated conditions. At any rate, even the strongest recorded ground motions were more than a factor of 2 weaker than any recognized damage threshold, although the associated airblast damage levels were significant.

DISCUSSION

Aerial photographs of the destroyed PEPCON plant and vicinity have allowed a reconciliation between available maps of Henderson and Las Vegas so that suffiently accurate estimates of distances to various damage sites could be made. Also, they gave a fairly certain location for the largest explosion, in Storage Area B, which accounted for most of the damages. Information on the amounts of

AP stored in various locations around the plant allowed the conclusion that 1500-tons (1385-Mg) AP furnished the source for the largest explosion. The sequence of explosions that occurred, according to accounts by plant workers, can also be guessed at from these photographs.

The general appearance of damage to the nearest residential development, in Arroyo Grande Estates, indicated that the order of 3.5-kPa (0.5-psi) airblast overpressure must have struck there. At 2-km distance, this leads to an estimated airblast source strength of 1-kt NE free-air burst, or 250-t HE surface burst, Standard explosion. Substantial estimation error bands for this damage interpretation indicate that this is not in significant disagreement with a 500-t HE estimate made from close-in phenomena.

Weather observations of southerly winds at the time of the accident indicate that near Standard, crosswind propagation would have been likely toward Arroyo Grande, so no significant weather-dependent adjustment is necessary in this yield estimate. It is not possible, from the only upper air observations at Desert Rock, 100 km northwest, to judge whether there was focused ducting of the blast wave, although downwind enhancement of northward propagation across Las Vegas was likely.

Other window damage observations, to 15-km distances, generally scattered around a 1-kt NE overpressure-distance curve, with random deviations caused by turbulent atmospheric details, well-known large scatter in glass plate failure characteristics, pane orientation and blast reflecting variations variations, as well as window installation details and the local environment of building reflectors, refractors, and diffractors. Many further damage measurements were made but not yet analyzed. They may provide some refinement to an overpressure pattern and increased confidence in final conclusions.

Seismic records have contributed information for estimating shot-times for the two largest shots, as well as a comparison of acceleration amplitudes from the "first" and "third" explosions, which appears to show that the first explosion was more than a factor of 3 smaller in yield than the later and largest explosion. They also provide independent estimates of airblast propagation velocities which agree quite well with the value determined from the surface weather report. It has not, however, been possible to determine reasonable ground wave velocities because, apparently, seismic time recordings are not closely synchronized. Ground wave arrival times from the first shot at S-3 and S-5 are needed to allow a simultaneous solution for all 24 unknown variables, but they were not triggered to record. If they had been, along with both ground wave arrivals at S-4 and S-6, there would have been a two point excess margin for statistical fitting, but that was unfortunately not the case.

Dividing the apparent airblast yield, 250-t HE, by the available material in Storage Area B, 1500-t AP, gives a TNT equivalence of 1/6 for AP. This figure is within the range of other estimates from 0.1 to 0.38, but it is at total variance with the provided wisdom that AP does not detonate and need not be treated as an explosive.

CONCLUSIONS

Several hours of fire and numerous explosions of various sizes destroyed the PEPCON AP rocket fuel component plant. A total of about 4 kt (3.85 Gg) of AP was involved. The largest single explosion occurred nearly half an hour after the fire started, and four minutes after the first significant explosion, in a collection of approximately 1.5 kt (1.385 Gg) of AP.

Damage to surrounding communities indicated an airblast from about 0.25-kt of TNT, surface burst, equivalent to a 1-kt nuclear explosion in free air, a Standard NE source.

The TNT explosion equivalence of AP appears to have been near 1/6, although it could have been a factor of 2 higher, considering uncertainties in our estimate.

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Table 1. Upper Air Conditions, Las Vegas, NV, 0500 PDT, May 4, 1988.

Las Vegas surface observation at 1047 PST May 4, 1988, plus Desert Rock Raob at 1200 UT May 4, 1988.

MSL Altitude (ft)	Pressure (mb)	Temperature (°C)	Dew Point (°C)	Wind Direction (Deg)	Wind Speed (knots)
900.000	941.000	23.9	-4.4	180.0	14.0
3400.000	895.000	12.4	6.1	120.0	2.0
3668.924	883.000	16.8	9.6	146.9	9.2
4000.000	872.549	16.0	8.8	180.0	18.0
4728.000	850.000	14.2	7.1	185.0	19.0
6000.000	810.861	10.8	4.0	190.0	20.0
7000.000	781.360	8.2	1.5	190.0	22.0
8000.000	752.933	5.6	-0.9	190.0	28.0
9000.000	725.541	2.9	-3.3	190.0	29.0
9967.000	700.000	0.4	-5.7	190.0	30.0
11680.246	653.000	-2.9	-8.9	198.4	35.9
12000.000	644.584	-3.5	-10.1	200.0	37.0
12721.130	626.000	-4.7	-12.7	207.2	37.7
13440.304	608.000	-5.9	-12.3	214.4	38.4
13849.100	598.000	-6.7	-12.3	218.5	38.8
13973.072	595.000	-6.7	-12.9	219.7	39.0
14000.000	594.350	-6.8	-13.0	220.0	39.0
14645.003	579.000	-8.3	-15.2	221.6	40.6
16000.000	548.031	-11.7	-16.1	225.0	44.0
17058.330	525.000	-14.3	-16.8	227.3	46.3
18261.000	500.000	-17.3	-19.0	230.0	49.0
23917.000	400.000	-29.1	-51.3	230.0	57.0
27000.000	349.430	-36.3	-46.2	230.0	57.0
28513.295	327.000	-39.9	-43.7	230.0	56.1
30479.000	300.000	-44.9	0.0	230.0	55.0
31000.000	293.225	-46.2	0.0	230.0	68.0

Table 2. Upper Air Conditions, Las Vegas, NV, 1700 PDT, May 4, 1988.

Las Vegas surface observation at 1147 PDT May 4, 1988, plus Desert Rock Raob at 0000 UT May 5, 1988.

MSL Altitude (ft)	Pressure (mb)	Temperature (°C)	Dew Point (°C)	Wind Direction (Deg)	Wind Speed (knots)
1900.000	941.000	23.9	-4.4	180.0	14.0
3400.000	895.000	20.4	12.7	210.0	22.0
4000.000	872.850	18.2	10.3	195.0	28.0
4741.000	850.000	15.4	7.4	200.0	29.0
6000.000	811.396	12.0	4.2	200.0	31.0
7000.000	781.986	9.2	1.7	205.0	32.0
8000.000	753.642	6.5	-0.9	210.0	32.0
9000.000	726.326	3.7	-3.4	210.0	34.0
9124.324	723.000	3.4	-3.7	210.6	34.5
10000.000	700.000	3.2	-4.8	215.0	38.0
11823.016	652.000	-0.1	-7.9	205.9	34.4
12000.000	647.519	-0.6	-8.3	205.0	34.0
14000.000	598.973	-5.9	-13.1	205.0	45.0
16000.000	554.066	-11.1	-17.9	215.0	41.0
17000.000	532.891	-13.8	-20.3	215.0	42.0
18635.000	500.000	-18.1	-24.2	210.0	50.0
20000.000	472.319	-21.2	-27.2	205.0	60.0
20633.377	460.000	-22.7	-28.6	205.0	63.8
20948.043	454.000	-23.7	-28.4	205.0	65.7
21000.000	453.017	-23.8	-28.4	205.0	66.0
22586.490	424.000	-25.7	-28.3	207.7	64.4
23983.000	400.000	-29.1	-32.6	210.0	63.0
25000.000	382.384	-31.8	-35.6	210.0	64.0
28054.793	334.000	-39.9	-44.6	210.0	74.6
30479.000	300.000	-44.7	0.0	210.0	83.0

Table 3. Upper Air Conditions, Las Vegas, NV, 0500 PDT, May 5, 1988.

Las Vegas surface observation at 1147 PDT May 4, 1988, plus Desert Rock Raob at 1200 UT May 5, 1988.

MSL Altitude (ft)	Pressure (mb)	Temperature (°C)	Dew Point (°C)	Wind Direction (Deg)	Wind Speed (knots)
1900.000	941.000	23.9	-4.4	180.0	14.0
3400.000	893.000	15.2	7.8	210.0	22.0
4000.000	871.218	13.5	5.8	205.0	27.0
4672.000	850.000	11.6	3.6	205.0	32.0
6000.000	808.935	8.6	1.0	210.0	37.0
7000.000	779.327	6.4	-0.9	210.0	38.0
8000.000	750.803	4.1	-2.8	210.0	39.0
9000.000	723.323	1.9	-4.7	200.0	39.0
9879.000	700.000	-0.1	-6.4	190.0	40.0
11000.000	669.707	-2.6	-9.0	185.0	44.0
12000.000	643.793	-4.8	-11.2	190.0	45.0
12508.582	631.000	-5.9	-12.4	191.3	47.0
12710.168	626.000	-6.1	-12.1	191.8	47.8
14000.000	594.933	-9.2	-14.6	195.0	53.0
16000.000	549.781	-14.0	-18.6	195.0	50.0
18405.000	500.000	-19.7	-23.3	200.0	59.0
19377.330	480.000	-20.9	-26.5	200.0	62.7
20000.000	467.614	-22.6	-26.3	200.0	65.0
20651.361	455.000	-24.3	-26.1	198.2	67.3
23720.000	400.000	-31.3	-32.2	190.0	78.0
25000.000	377.960	-34.4	-37.5	195.0	81.0
25117.393	376.000	-34.7	-38.0	195.1	81.7
26479.029	354.000	-37.1	-42.9	196.7	89.5
27792.420	334.000	-40.1	-45.8	198.2	97.1
30217.000	300.000	-44.1	0.0	201.0	111.0

Table 4. Upper Air Conditions, Las Vegas, NV, 1151 PDT, May 4, 1988.

Sounding interpolated between 0500 PDT and 1700 PDT raobs for May 4, 1988.

MSL Altitude (ft)	Pressure (mb)	Temperature (°C)	Dew Point (°C)	Wind Direction (Deg)	Wind Speed (knots)
1900.000	941.000	23.9	-4.4	180.0	14.0
3400.000	893.000	18.9	7.8	170.0	13.7
6000.000	808.935	11.5	1.0	196.0	26.4
7000.000	779.327	8.8	-0.9	199.0	27.8
8000.000	750.803	6.1	-2.8	202.0	30.3
9000.000	723.323	3.4	-4.7	202.0	31.9
10000.000	700.000	2.0	-6.4	205.0	34.7
11823.016	652.000	-0.1	-7.9	205.9	34.4
12000.000	647.519	-0.6	-8.3	205.0	34.0
14000.000	598.973	-5.9	-13.1	205.0	45.0
16000.000	554.066	-11.1	-17.9	215.0	41.0
17000.000	532.891	-13.8	-20.3	215.0	42.0
18635.000	500.000	-18.1	-24.2	210.0	50.0
20000.000	472.319	-21.2	-27.2	205.0	60.0
20633.377	460.000	-22.7	-28.6	205.0	63.8
20948.043	454.000	-23.7	-28.4	205.0	65.7
21000.000	453.017	-23.8	-28.4	205.0	66.0
22586.490	424.000	-25.7	-28.3	207.7	64.4
23983.000	400.000	-29.1	-32.6	210.0	63.0
25000.000	382.384	-31.8	-35.6	210.0	64.0
28054.793	334.000	-39.9	-44.6	210.0	74.6
30479.000	300.000	-44.7	0.0	210.0	83.0

Table 5. Calculations from Medina data for 'Average' pane size. (See text, Equations 1-3, for symbol definitions.)

	Pane Size Category				Totals	
	A	B	C	D	(1)	(2)
f (psi)	14,816	14,816	9,600	9,600		
f (MPa)	102.15	102.15	66.19	66.19	102.15	102.15
H (in)	0.08	0.08	1/4	5/16	0.08	0.08
H (mm)	2.056	2.056	6.425	8.031	2.056	2.056
A (ft^2)	1	6	25	50	3.93	4.05
A (m^2)	0.0951	0.5707	2.3778	4.7555	0.3742	0.3856
D	1	1	2	2	1	1
c	4	1	1	1	1	1
b (Pa)	4152	2768	2102	1642	4221	4097

(1) Selected Areas

	A	B	C	D	(1)	(2)
Population (panes)	749,900/4	720,300	11,700	3,770	1,485,670	
Broken (panes)	127	377	82	53	639	
Probability	0.000677	0.000523	0.007009	0.014058	0.000430	
n (σ's)	-3.21	-3.27	-2.45	-2.20	-3.33	
Est'd Δp (Pa)	219.2	138.2	221.7	219.5	199.7	

(2) San Antonio Totals

	A	B	C	D	(1)	(2)
Population(panes)	7,001,500/4	5,407,700	92,400	26,300		12,527,900
Broken (panes)	346	1,921	349	244		2,860
Probability	0.000198	0.000355	0.003777	0.009278		0.0002283
n (σ's)	-3.54	-3.39	-2.67	-2.36		-3.51
Est'd Δp (Pa)	162.0	123.9	181.6	189.6		164.3

Table 6. Mean breaking loads for four window pane size categories. (See text, Equations 1-3, for symbol definitions.)

	Pane Size Category A	B	C	D
f_i (MPa)	102.15	102.15	66.19	66.19
H_i (mm)	2.056	2.056	6.425	8.031
A_i (m^2)	0.0951	0.5707	2.3778	4.7555
D_i	1	1	2	2
c_i	4	1	1	1
B_i (kPa)	7.50*	5.00	3.80	2.97

* - For one broken pane per four exposed (one casement window).

Table 7. Mean breaking loads for 1 ft^2 (0.0951 m^2) panes of popular glasses.

For other square plate areas, divide by area (ft^2).

	Common Glass		Plate Glass Annealed		Tempered*
	SS	DS	3/16	1/4	1/4
Thickness (in):	0.08	0.125	0.1875	0.25	0.25
B (kPa)	30	73	53	95	380

* - Tempered glass strength is approximately four times annealed glass strength.

Table 8. Estimated incident overpressures for survey-observed damage frequencies.

Assumed: a. Half of windows visible to observer.
b. 24 panes, each 6 ft^2 (0.5701 m^2) SS glass, per house.

Broken Panes per House	Damage Probability	σ's	Δp (Pa)
10	0.9583	0.966	6058
6	0.5000	0.000	2500
5	0.4167	-0.210	2062
4	0.3333	-0.431	1685
3	0.2500	-0.674	1348
2	0.1667	-0.967	1030
1	0.08333	-1.383	704
1/2	0.04167	-1.731	512
1/3	0.02778	-1.915	433
1/4	0.02083	-2.037	386
1/5	0.01667	-2.128	356
1/10	0.00833	-2.394	279
1/20	0.00417	-2.637	223
1/50	0.00167	-2.933	170
1/100	0.000833	-3.14	141
1/1000	8.33×10^{-5}	-3.76	80
1/10000	8.33×10^{-6}	-4.28	50

Table 9. Analysis of broken panes in window damage incidents.

Location	Distance (m)	No. Brkn	No. Expsd	Range of Probability P1	P2	(1 Sq.Ft.) B1 (kPa)	B2	Pane Characteristics Width (in)	Length (in)	Thick (in)	Type	Area (sq.ft)	Dyn. Amp.	Breaking DP1 (Pa)	DP2
Arroyo Grande Country Club	2039														
Lounge		1	3	0.167	0.5	160	380	67	70	1/4	Tmp	32.57	2	2456	5834
Billiard Room		3	3	>0.833		>125		46	70	3/16	Ann	22.36	2	>5590	
Billiard Room		0	3	<0.167		<21		22	70	3/16	Ann	10.69	1	<1964	
Kitchen		1	2	0.250	0.750	16	57	36	48	0.08	SS	12.00	1	1333	4750
Office		1	2	0.250	0.750	28	100	36	60	3/16	Ann	15.00	1	1867	6667
Silver Spring Office Trailer	2720	1	4	0.125	0.375	10	22	18	30	0.08	SS	3.75	1	2667	5867
Crest & Buchanan Streets	3210	6	16	0.348	0.406	20.5	23.5	30	40	0.08	SS	8.33	1	2460	2820
Water Street															
Assumption A	4400	16	16	>0.968		>523		60	60	1/4	Ann	25.00	2	>10469	
Assumption B						>292				3/16	Ann			>5841	
Assumption C		14	16	0.848	0.906	133.7	177.6			3/16	Ann			2674	3553
Cattle Baron's Casino	4200	8	12	0.625	0.708	130.0	150.0	48	84	1/4	Ann	28.00	2	2321	2679
McDonald's	4773	1	1	>0.5		>95.0		84	96	1/4	Ann	56.00	2	>848	
				<0.031		<180.0		36	48	1/4	Ann	12.00	1	<1417	
Swim Sport (vacant)	12270	3	6	0.417	0.583	42.0	64.0	48	60	3/16	Ann	20.00	2	1050	1680
Hilton Hotel	15190	14	120	0.112	0.121	31.0	33.0	42	72	1/4	Ann	21.00	2	738	786
Desert Inn Road & Maryland Pkwy	13760	2	7	0.214	0.357	46.0	67.0	76	104	1/4	Ann	54.89	2	419	610
		1	4	0.125	0.375	37.0	71.0	85	109	1/4	Ann	64.34	2	288	552
Sahara Blvd.															
Bertha's	14970	2	3	0.375	0.625	70.0	130.0	79	139	1/4	Ann	76.25	2	459	852
Christensen's	14980	1	6	0.083	0.250	24.0	50.0	90	98	1/4	Ann	61.25	2	196	408

Table 10. Analysis of data on residential window damage occurrences.

Location	Distance (km)	Windows Broken per House	Incident Overpressure (Pa)
Albany Way	2.9	1	700
Mountain View Road	4.2 - 4.7	0.5	500
Heather Drive	6	<1/6	<330
Boulder Highway & Flamingo Road	9	1/6	330

Table 11. Ammonium perchlorate quantities in PEPCON storage areas.

nn - Provided Values (nn) - Assumed Values [nn] - Deduced Values

	Storage Type							
Storage Area	5000# Bins	4500# Bins	2000# Bins	Total Bins	2300# Bags	550# Barrels	250# Drums	Totals (lb)
A	[0]	[163]	[0]	163	26	990	0	1,337,800
B	(240)	(375)	0	615	0	304	[0]	[3,054,700]
C	[0]	[1]	[6]	[7]	0	7306	(260)	[4,099,800]
Total Nos.	240	539	6	785	26	8600	260	
Total Weight (tons)	600	1212.75	6	1818.75	29.9	2365	32.5	4246.15

Table 12. Seismic station signal times and analyzed results. All arrivals, T + 11 hours (PDT).

STA	DISTANCES (meters) MAP SHOT #1	ADJUSTED SHOT #1	ADJUSTED SHOT #2	ARRIVAL TIMES (sec) SHOT #1 GROUND	SHOT #1 AIR	SHOT #2 GROUND	SHOT #2 AIR	ARRIVAL ERROR (sec) GROUND #1	GROUND #2	AIR #1	AIR #2	GROUND WAVE VELOCITY (m/s) #1	#2
1	3624.6	3595.3	3708.7	3215.711	3225.194	3455.793	3465.257	-0.240	-0.161	0.028	-0.027	10017.795	8114.704
2	12753.8	12779.3	12892.7	3217.847	3251.022	3457.756	3491.057	0.365	0.271	0.005	-0.005	5122.229	5327.208
3	14587.7	14621.9	14735.3	0.000	3256.209	3459.416	3496.241	0.000	1.624	0.001	0.000	0.000	3611.530
4	15188.3	15242.4	15355.8	0.000	3257.953	0.000	3497.989	0.000	0.000	-0.003	0.004	0.000	0.000
5	16215.7	16242.2	16355.6	0.000	3260.769	3461.678	3500.800	0.000	3.616	-0.004	0.005	0.000	2578.917
6	18197.2	18272.7	18386.1	0.000	3266.486	0.000	3506.522	0.000	0.000	-0.008	0.018	0.000	0.000
7	18197.2	18272.7	18386.1	0.000	3265.190	0.000	3505.249	0.000	0.000	-1.304	-1.255	0.000	0.000
8	19437.6	19573.3	19686.7	3216.329	3270.147	3456.356	3510.173	-2.285	-2.261	-0.012	0.013	20027.990	19295.672

NOTES:

Record reading error (+/-) for times, Stations 1-7: 0.002 sec
Station 8 : 0.250 sec

Stations 6 & 7, basement and roof readings, respectively.

Ground wave zeroes (0.000) indicate recorder not triggered by wave.

Table 13. Analysed results from airblast arrival times.

Station S-	Positive Phase Duration (sec) Shot #1	#2	Signal Separation Times (sec) Ground	Air	S-1 to S-n Air Wave Sound Velocity (m/s) Shot #1	#2
1	0.323	0.489	240.082	240.063		
2	0.364	0.557	239.909	240.035	354.85	355.62
3	0.368	0.564	0.000	240.032	354.74	355.45
4	0.370	0.566	0.000	240.036	354.74	355.37
5	0.371	0.569	0.000	240.031	354.68	355.32
6	0.375	0.575	0.000	240.036	354.59	355.13
7	0.375	0.575	0.000	240.059		
8	0.377	0.578	240.027	240.026	354.56	355.13
			Averaged sound velocities (m/s):		354.69	355.34

Seven station averaged shot separation = 113.42 m
All signals, arrival time estimates, Std. Dev. (+/-) = 0.013 s
Shot times: 1100 PDT + 3215.352, 3455.336 s, respectively

Table. 14. Overpressure estimates from vertical ground motion seismic records.

Station S-	Shot	Arrival Times (min:sec)	Vertical Acceleration (m/sec.sq.)	Frequency (Hz)	Vertical Velocity (m/s)	Over-pressure (Pa)
1	1	53:45.194	-0.05300	14.98	0.005520	3140
	1'	56:25.733	-0.00125	11.89	0.000164	93
	2	57:45.257	-0.07500	12.01	0.009745	5540
2	1	54:11.022		4.27	0.000400	227
	2	58:11.057		4.27	0.000551	313
6	1	54:25.190	-0.000825	5.54	0.000232	132
	2	58:25.458	-0.000925	4.01	0.000360	205

Note: Stations #1 & #6 equipped with accelerometers.
Station #2 had vertical velocity sensor.

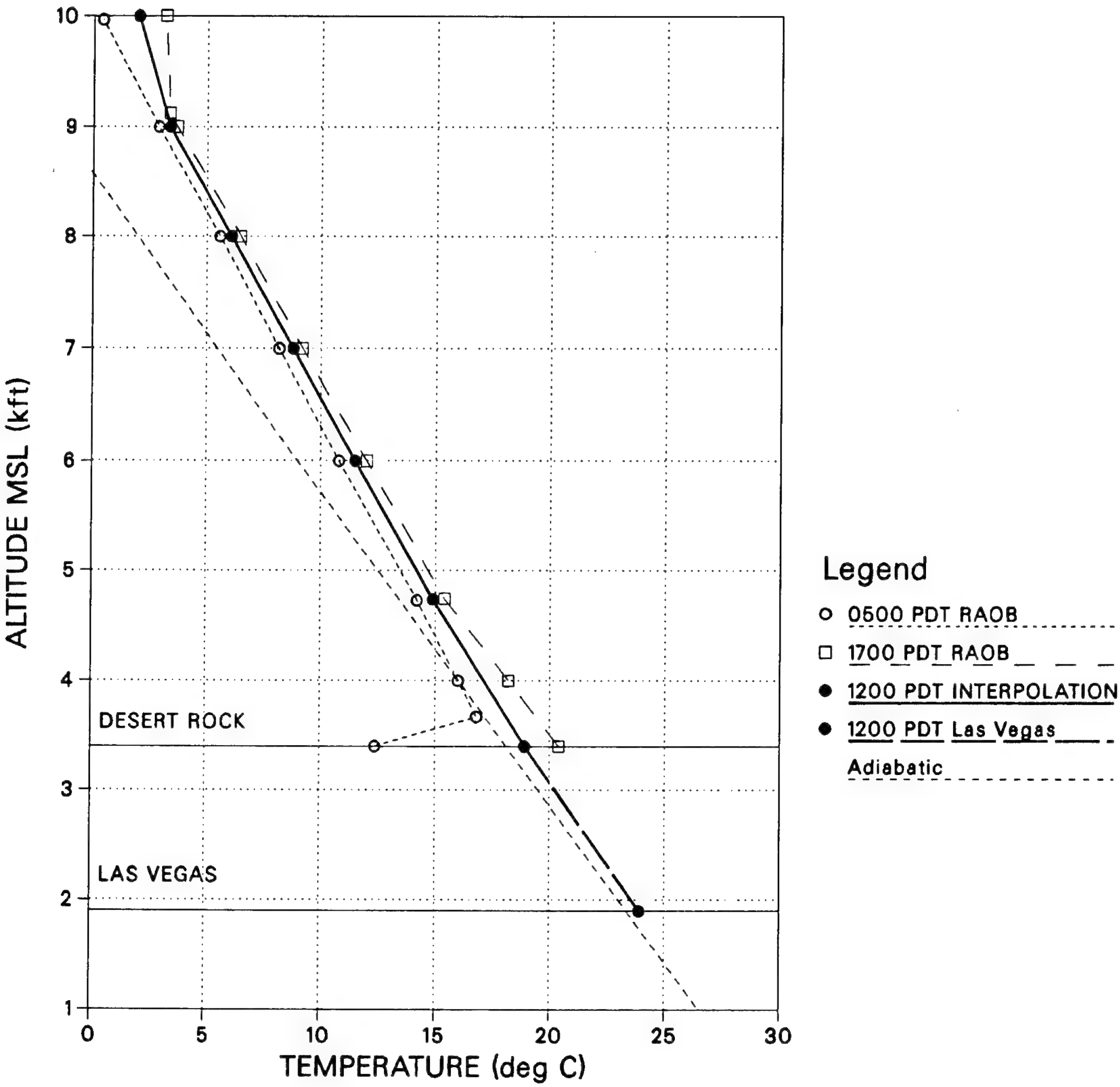

Figure 1. Temperature versus height curves, Las Vegas, Nevada, surface observations at 1200 PDT; Desert Rock radiosonde observations at 0500 & 1700 PDT, May 4, 1988.

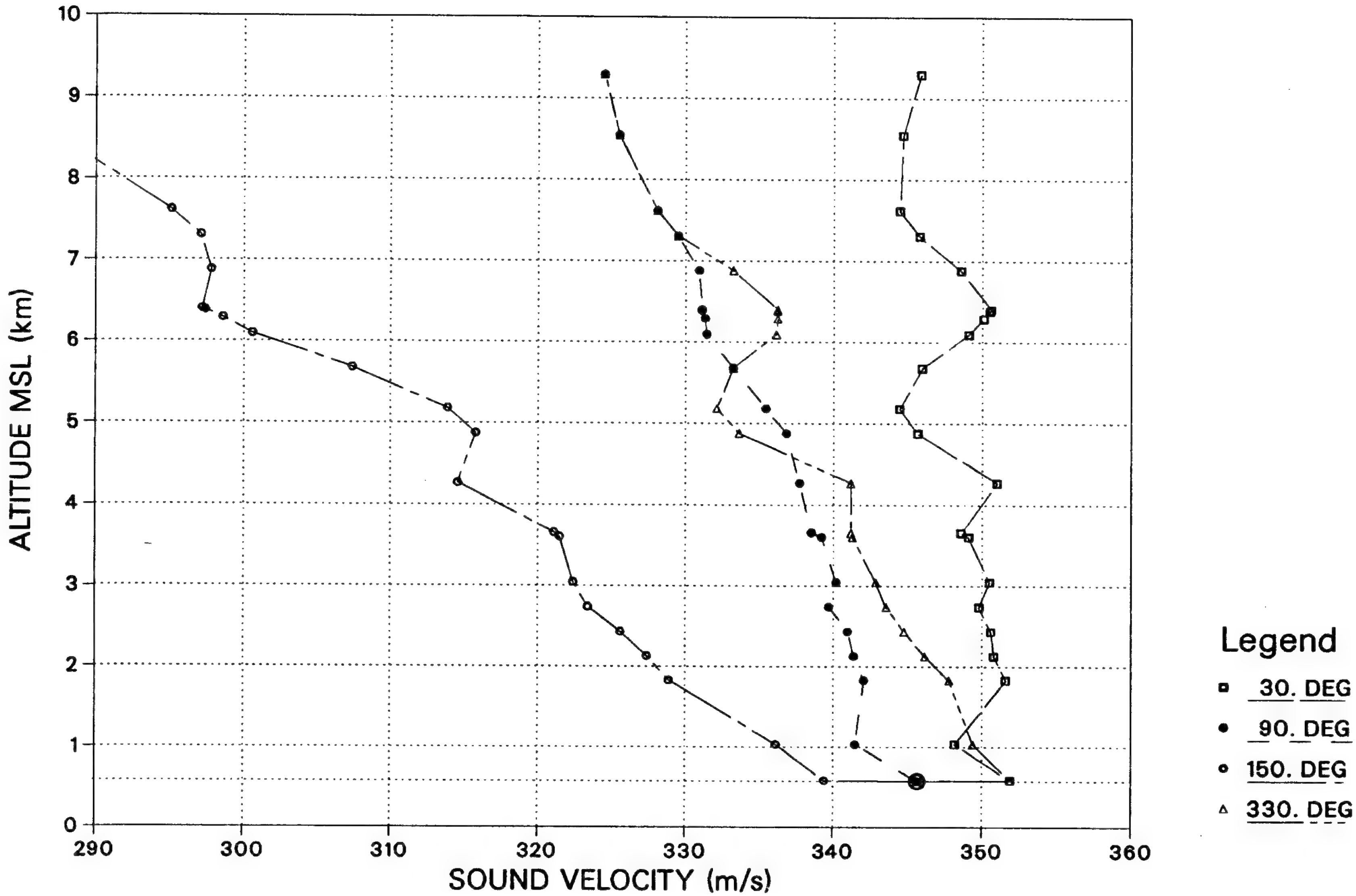

Figure 2. Sound velocity versus height curves; 30°, 90°, 150°, & 330° azimuths. Composite sounding for 1200 PDT, May 4, 1988; Las Vegas surface observation plus Desert Rock radiosondes at 0500 & 1700 PDT.

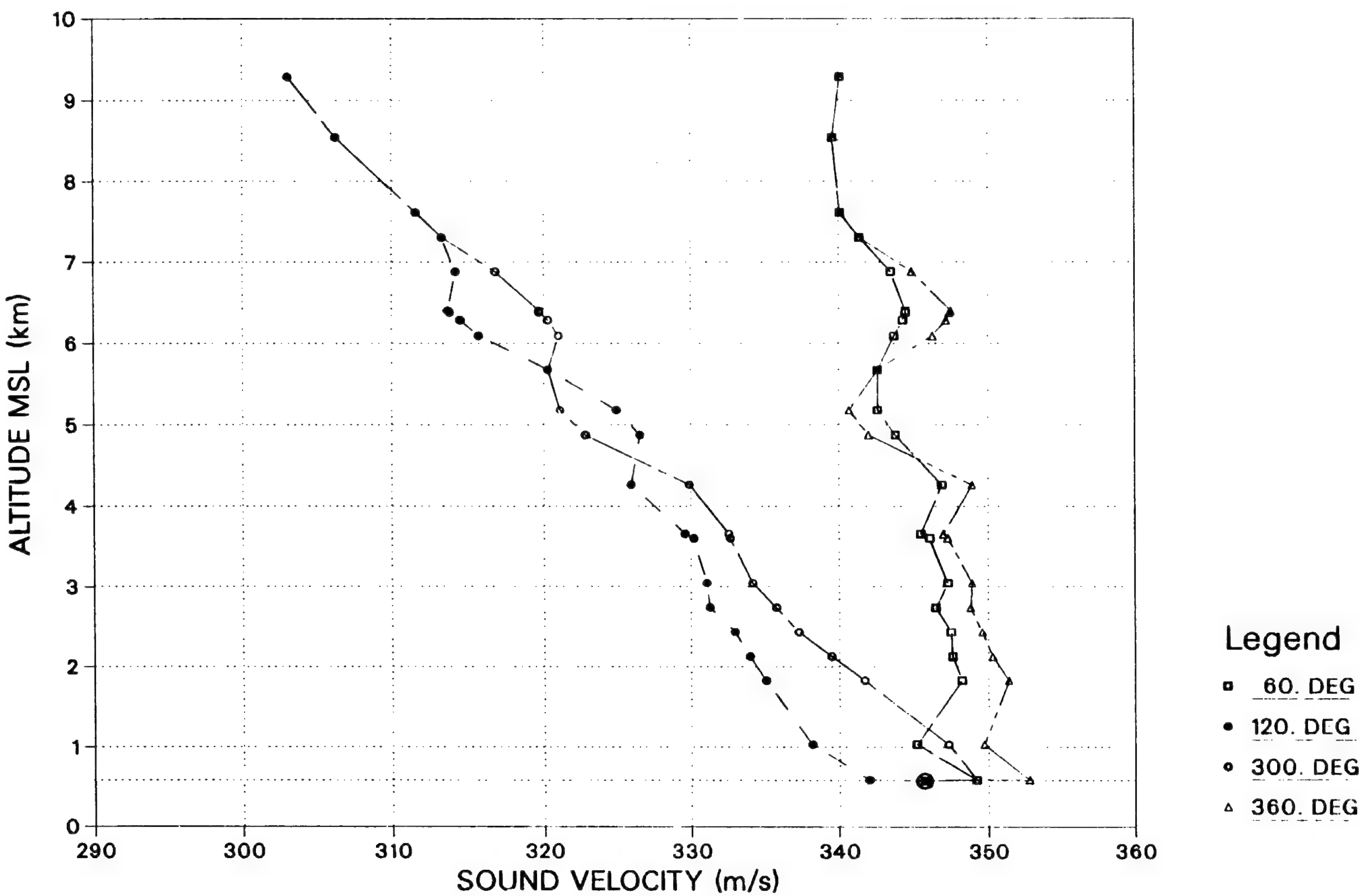

Figure 3. Sound velocity versus height curves; 60°, 120°, 300°, & 360° azimuths. Composite sounding for 1200 PDT, May 4, 1988; Las Vegas surface observation plus Desert Rock radiosondes at 0500 & 1700 PDT.

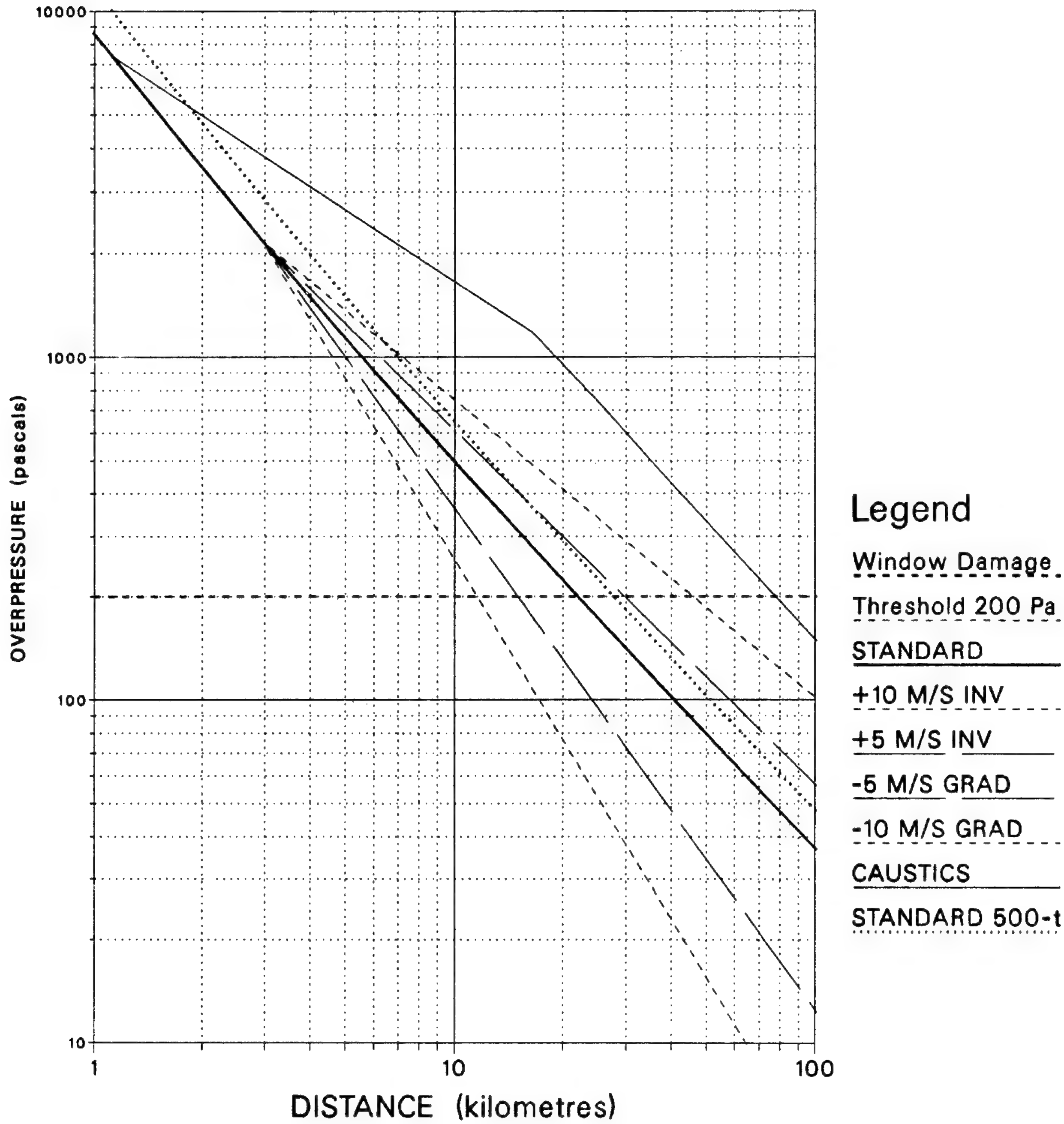

Figure 4. Airblast overpressure versus distance curves for 1-kt NE free-air burst (or 250-ton TNT surface burst), at 579 m MSL altitude, 94.1 kPa ambient pressure.

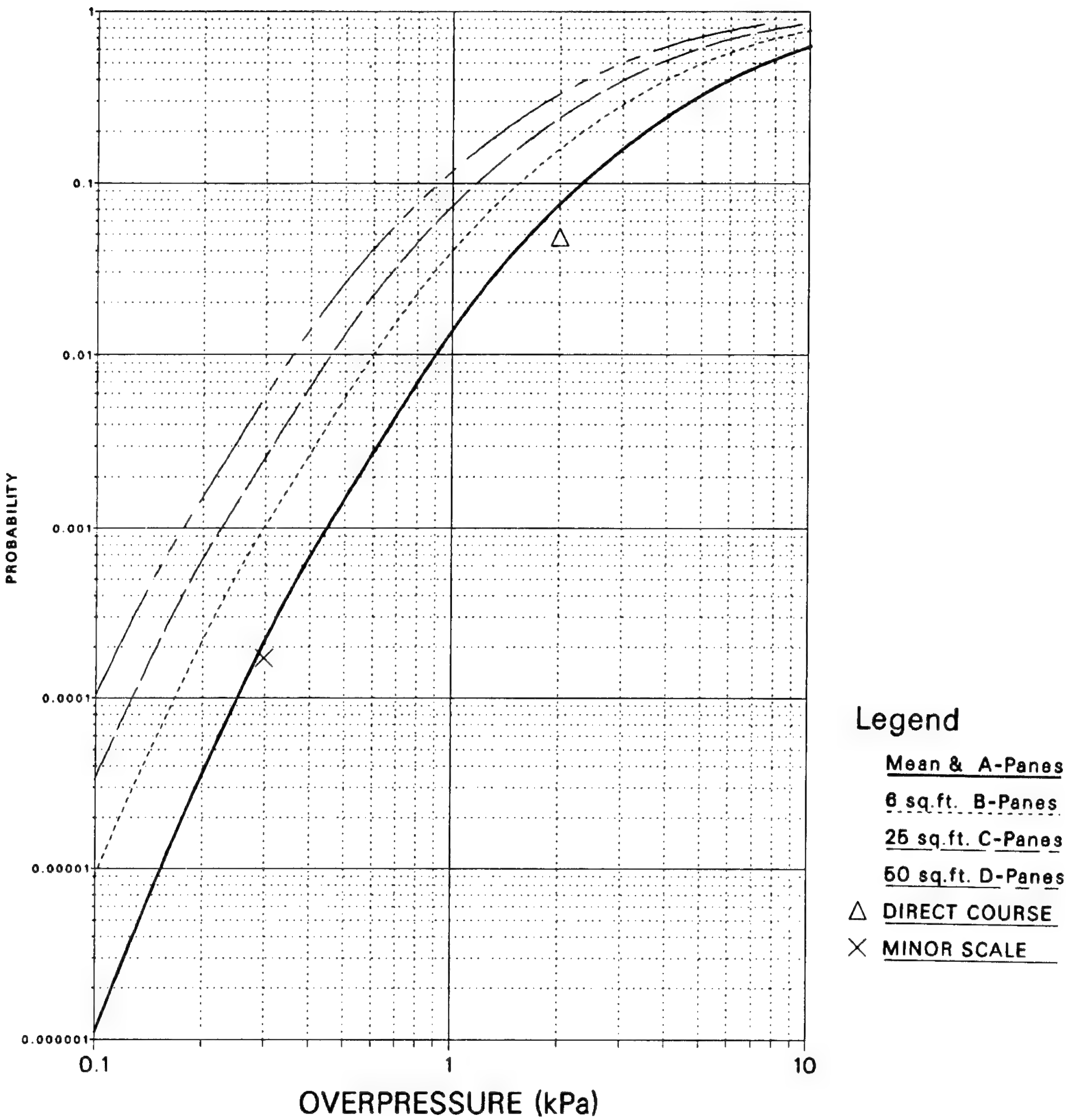

Figure 5. Window breakage probability versus incident side-on (gaged) overpressure. Mean curve based on 1964 San Antonio, Texas, window pane size distributions.

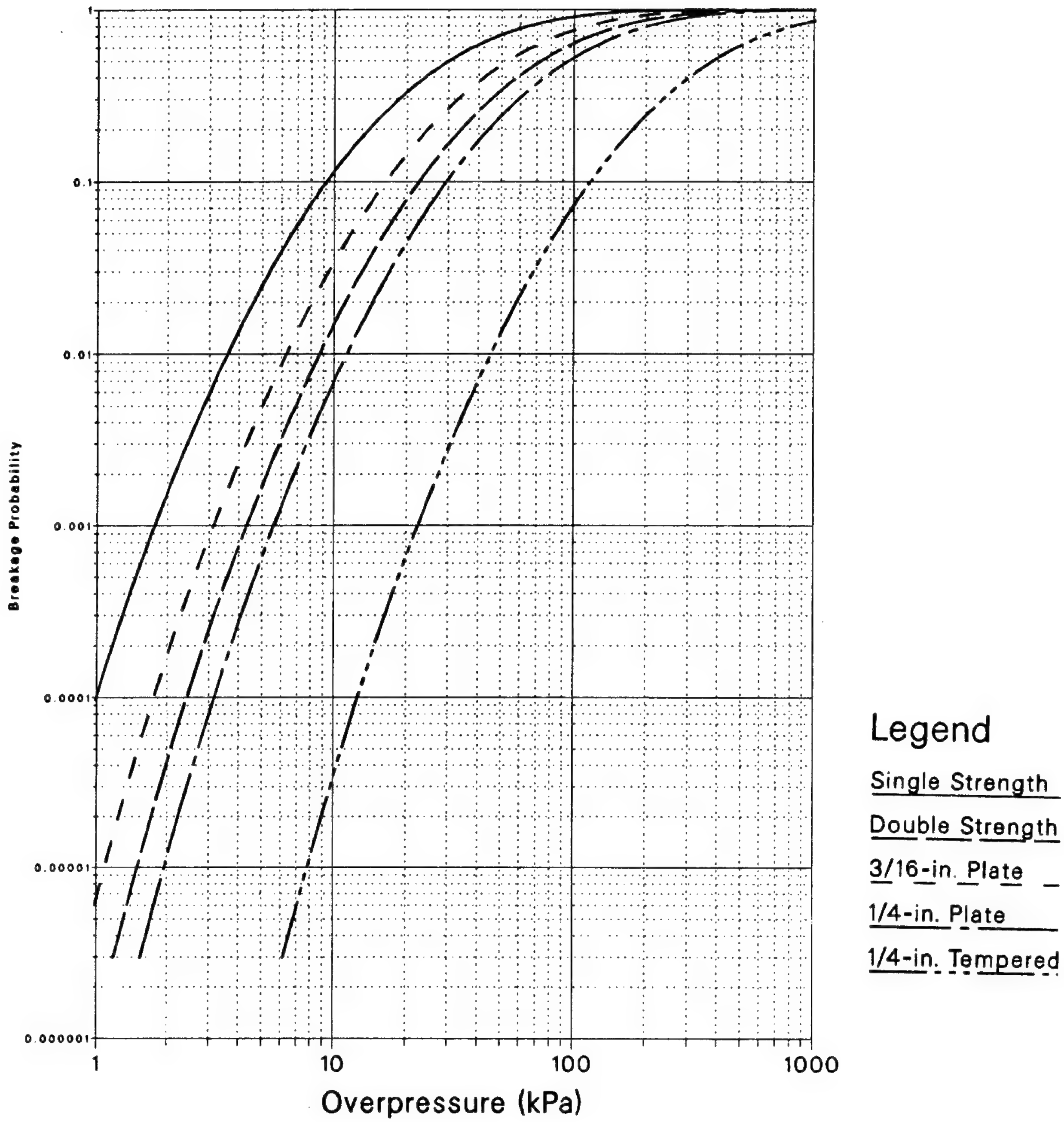

Figure 6. Window breakage probabilities normalized for 1 ft^2 pane area. For 10 ft^2 panes, divide overpressure by 10.

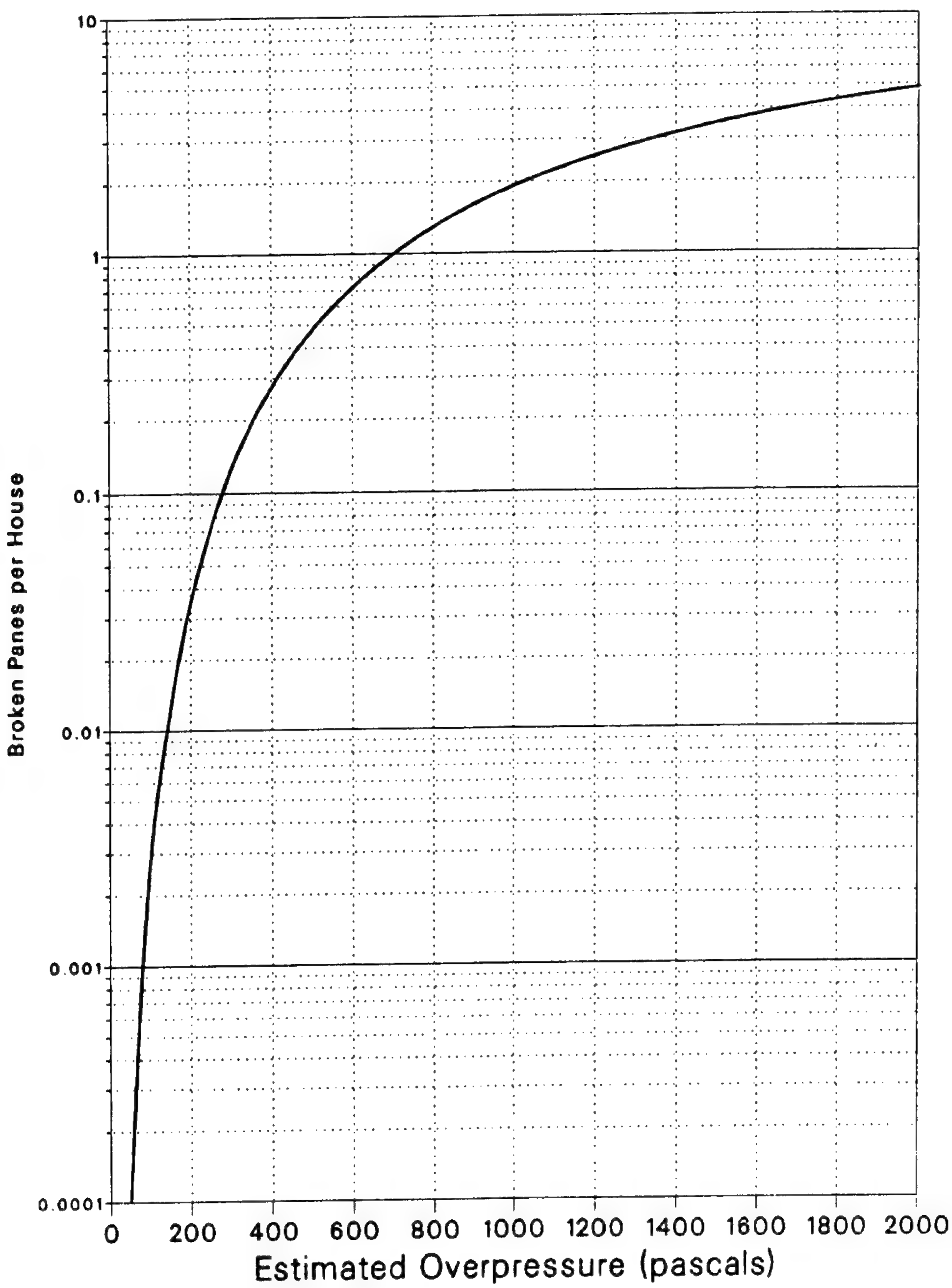

Figure 7. Broken window panes per house, visible from the street, versus incident airblast overpressure. (Curve adjusted for Las Vegas architectural practices).

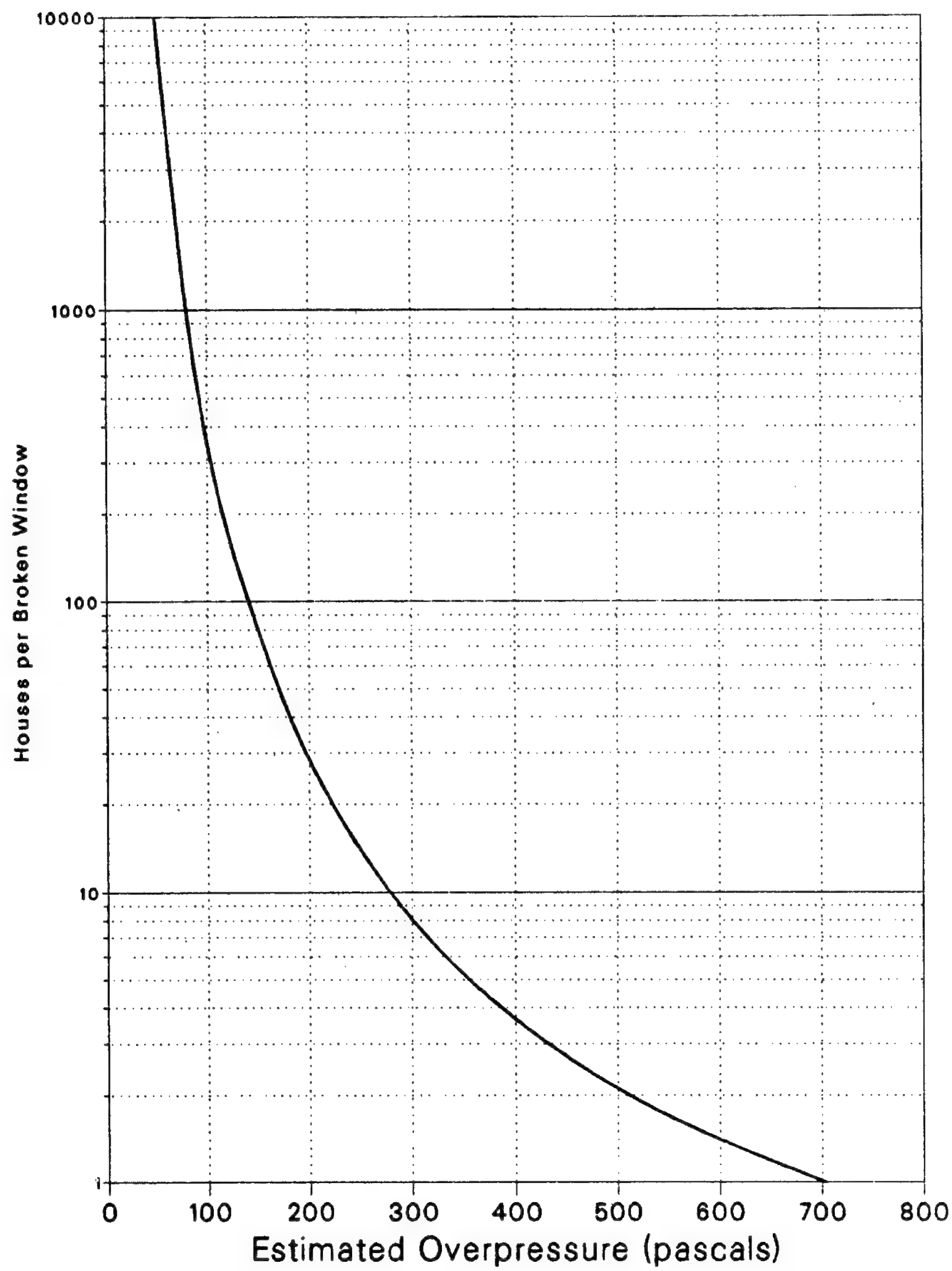

Figure 8. Number of houses per visible broken window pane, versus incident airblast overpressure. (Curve adjusted for Las Vegas architecture).

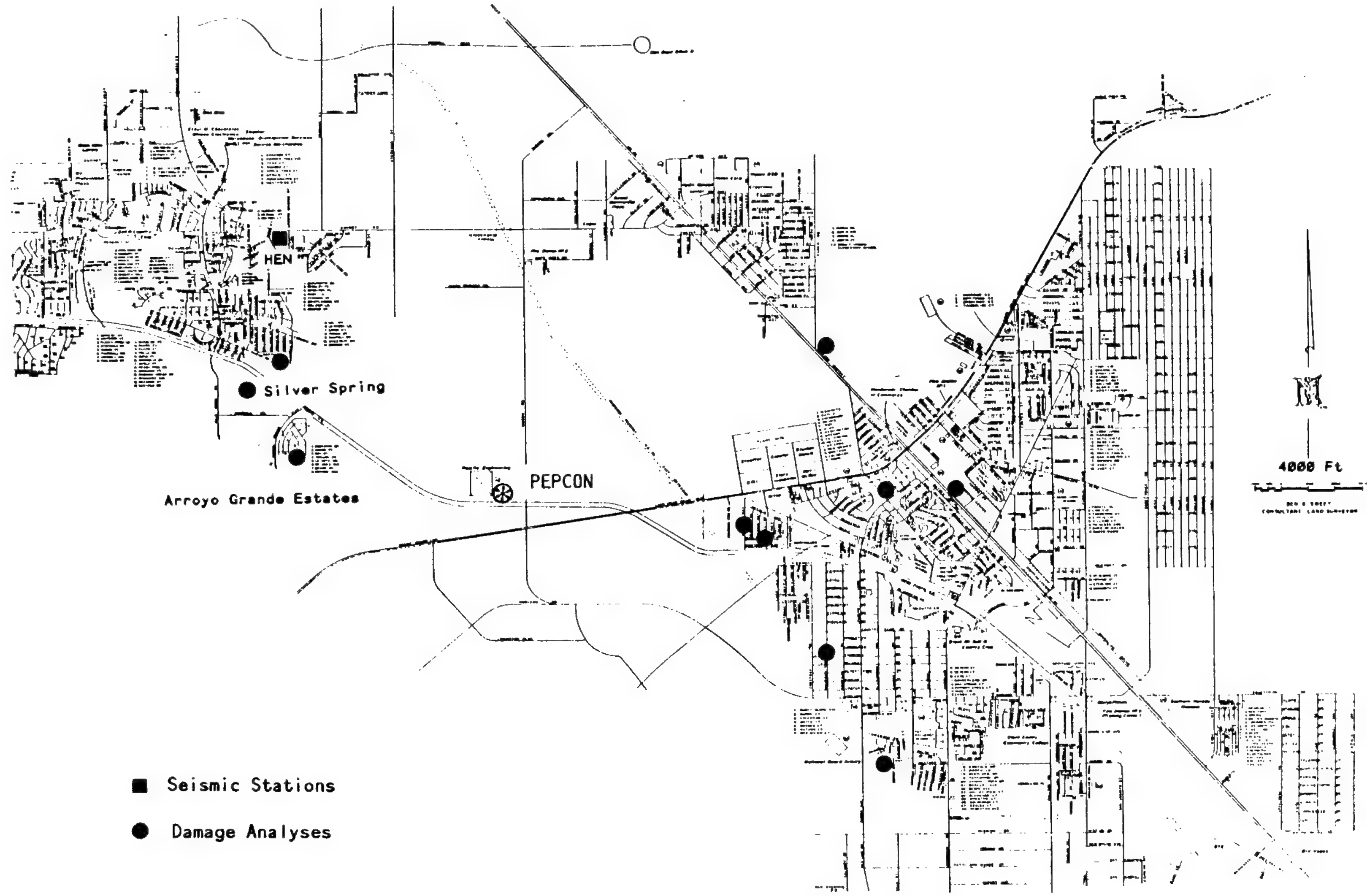

Figure 9. Street map of Henderson, Nevada, (from Henderson Chamber of Commerce), with explosion site and locations for damage analyses.

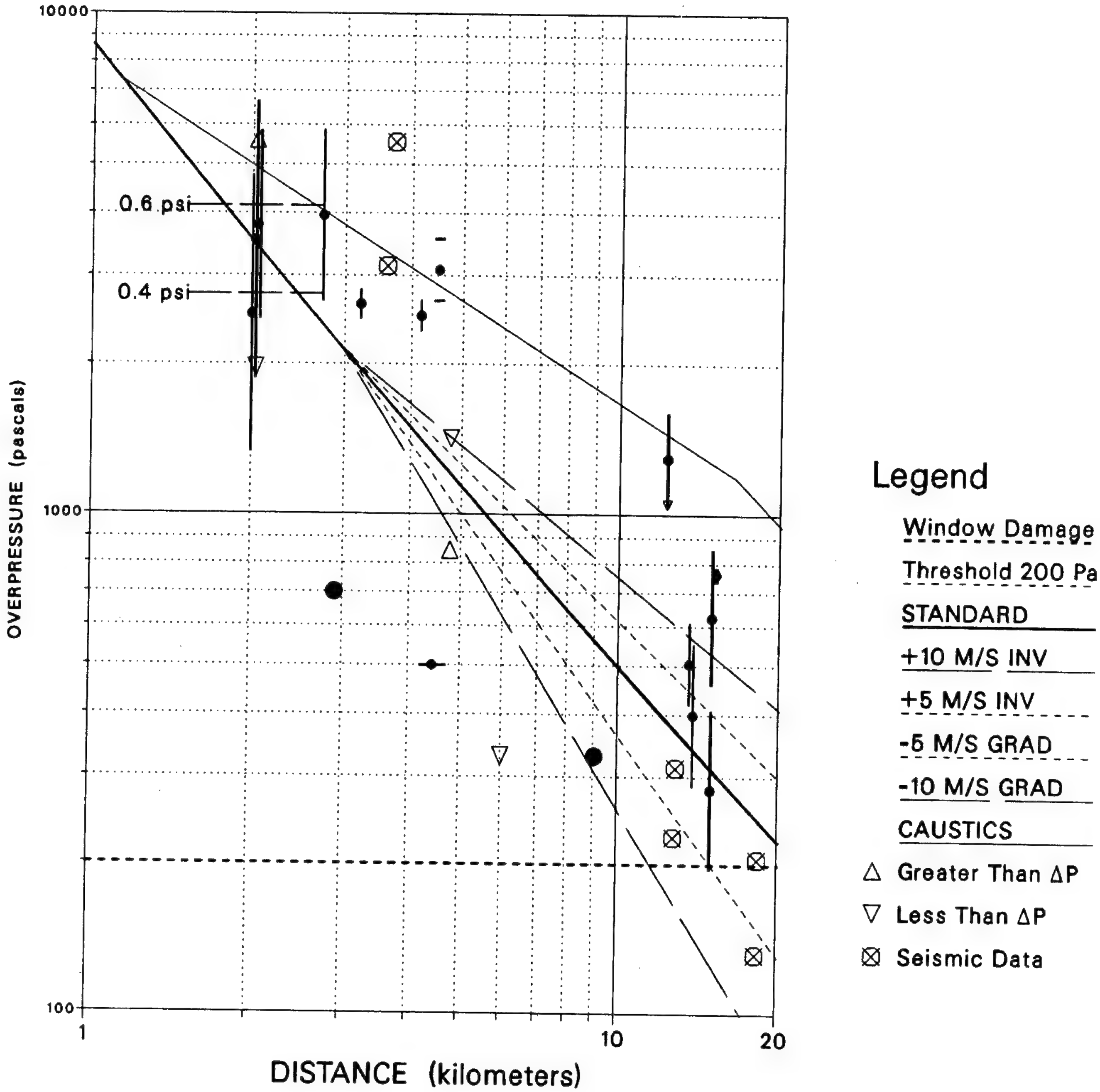

Figure 10. Airblast overpressure versus distance curves for 250-ton TNT surface burst at PEPCON, with data estimated from damage evaluations. (Vertical bars indicate range of overpressures needed to give observed damage probabilities).

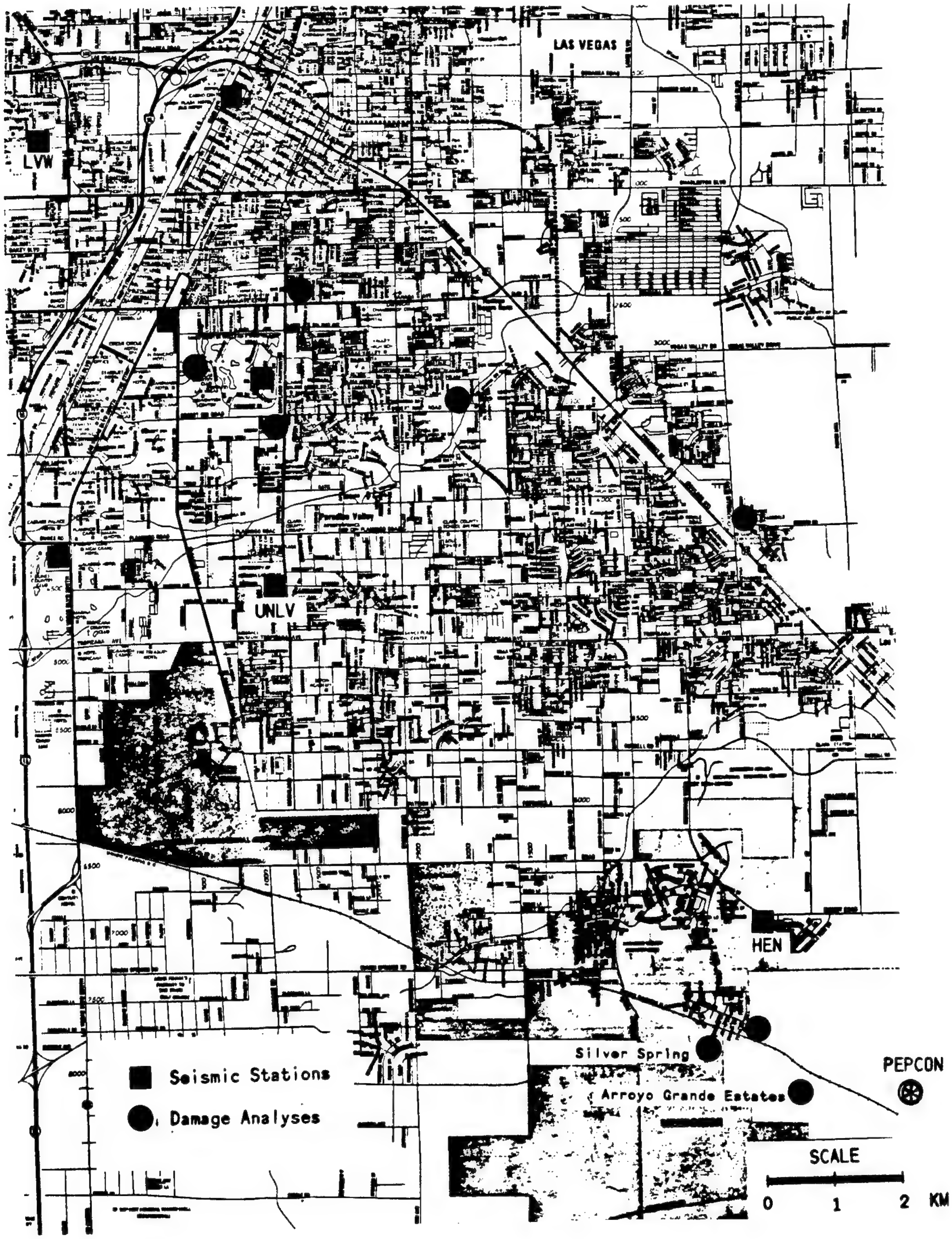

Figure 11. Street map of Las Vegas, Nevada (from Rand McNally), with explosion site and locations for damage analyses.

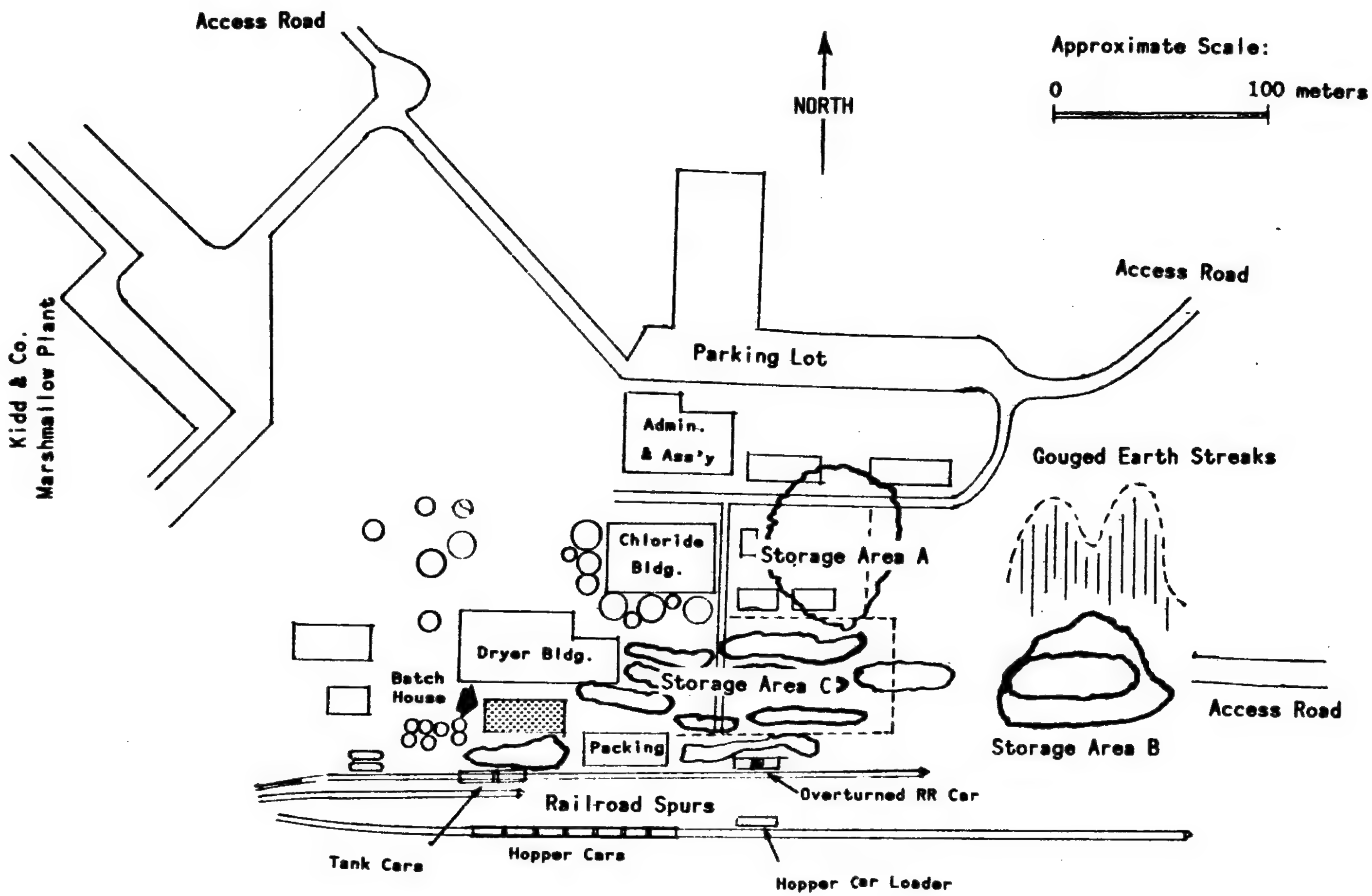

Figure 12. Sketch map of Pacific Engineering Company (PEPCON), Henderson, Nevada, with primary explosion damage features.

APPENDIX A. NOTES FROM INSPECTION OF DAMAGES FROM PEPCON EXPLOSION, TRANSCRIBED 5/17/88; J. W. REED, SNLA-7111.

(Directions and distances in parentheses added as available.)

Wednesday, May 4, 1988

Wednesday evening, May 4, 1988, on arrival in Las Vegas, I could not see any signs of reported damage to the airport doors, which had been "blown off their tracks". While flying past the burning explosion site it had not been clear that any significant crater had been formed. I immediately drove southeast from the airport to see what could be seen before dark. The closest residential development was Arroyo Grande Estates (2 km WNW), which showed considerable airblast damage. Their new Country Club building had most of the blast-facing windows smashed inward. Several ceiling panels had been torn down so that insulating wool was scattered throughout the building.

Their night security guard had been at home, north of Sam's Place on Boulder Highway (8.9 km NNW), sleeping when the first blast "knocked him out of bed". He went outside to see what was happening when the next blast came; the smoke cloud was clearly visible. Later, when he drove to work there were four road blocks to penetrate. I could not see many details in the burning site. The distance was estimated at about two miles by the guard.

Afterward I drove through an area of Santiago and Vallarta Avenues (3.1 km NW) where most notable was that all garage doors were bent or broken off. The populace was busy boarding up their broken windows. The radio declared a curfew would begin at 8 pm, so I drove to the Strip and El Morocco Hotel. It was too dark to see any damage en route. I managed to find copies of newspaper Extra Editions at the Desert Inn (DI) Hotel.

On TV there was continuous coverage of the incident, including a good video-camera record taken from a gravel plant about a mile NW from the site. This showed the "second" and "third" blasts with live commentaries. The explosion cloud did not appear to rise as high as could be expected but their telephoto lens apparently did not get the full vertical extent of the cloud. Subsequent conversation with Bob Bass (SNLA-7111) indicated a yellow-orange cloud extended above a much blacker cloud, but it was not shown on the video report as I recall it. Bass also recalled that the cloud top appeared at or above the Sunrise Peak (elev. 3367 ft) sight line from his location on Sahara Avenue between Paradise Road and Maryland Parkway (16 km NW).

Thursday, May 5, 1988

Thursday morning I met the Texas Tech people, W. P. Vann, and J. R. McDonald, both civil engineering professors, sponsored by the Patrick Air Force Base Range Safety Program to gather window damage data from disasters. We first drove to Holman's Engineering Supply Co., on West Charleston for maps. This shop is managed by Derek Hill, originally of Albuquerque. They had a free Henderson Chamber of Commerce map as well as a Rand McNally map of Las Vegas; between them, they covered the affected area. Another Holman

employee, Dave Medier, lived in Henderson until recently, and referred us to his friends Gary Johnson, of the Henderson C of C, and Ben Sweet, Civil Engineer, who had prepared the Henderson map.

Next we visited the National Weather Service Office, in the Las Vegas Hughes Terminal (the old LSV terminal), to obtain copies of their LSV surface weather observations for May 4, 1988, along with code reports of radiosonde balloon observations made at Desert Rock at 1200 UT (0500 PDT) May 4, 0000 UT and 1200 UT May 5, 1988. Unfortunately the elevation difference between these two stations will require some interpretation to estimate the actual wind and temperature structure that affected this blast. There were generally strong southerly winds aloft that gave about crosswind propagation toward Arroyo Grande Estates, thus allowing a weather-independent yield estimate based on damage observations. There probably was atmospheric refractive ducting and focusing toward the north and across Las Vegas.

We drove back to Arroyo Grande Estates for photos and measurements of window breakage in the Country Club (2 km WNW) and various mobile homes. This area began at 1.4 miles east of Green Valley Parkway, and extended 0.2 miles eastward. These modular homes had add-on garages, built with cheap, knotty 2"x4" framing, which were much damaged with broken studs and shifted roofs. Some interior wall panels were broken loose, and showed construction of fiberboard stapled to 1"x3" framing. In one house, a sliding patio door unit had both panels blown inward; they were lying unbroken on the floor, but the central mullion had been sheared off, thrown across the room, and impaled like a harpoon in the opposite wall. Another missile in another housing unit was created from a screen, which was blown inward as the window failed, partially folded and stuck in the wall across the room.

In the Country Club building on the east wall facing across their pool, there were three panels of tempered 1/4" glass, 67"x70", blown inward with two panels left unbroken on the floor and only one shattered. Three panes of 46"x70" annealed 3/16" plate were broken, but three panes of 22"x70" were not broken. In the kitchen, also facing the blast, one of two 36"x48" single-strength (SS) panes was blown in. An inside office had the door broken inward and one of two 36"x60" panes of 3/16" annealed glass were broken. On the west side of this building, windows were all blown outward, some with considerable frame distortion, after the blast passed through the building.

To the north along Green Valley Parkway, the next real estate development was Silver Springs (3.6 km WNW), but it only extended to 0.8 mile east of the Parkway. New construction facing east was moderately damaged, with about one-quarter of the windows broken, several doors torn off, and some south- and east-facing walls dished in. A construction foreman described being knocked across a porch (6 ft) into the wall by the third blast. An office trailer unit, very similar to some units at the MISTY PICTURE Admin Park, had one broken window pane of four exposed, of approximately 18"x30" glass. By this time most window damage was noted by the plywood panels nailed over empty window openings

Traveling north across the Union Pacific RR tracks and east along Warm Springs Road, it curved southeast to become Nuevo Road. Near the east end there was window damage and bent or broken garage doors in every home (3.1 km

NW). We were invited into one home where a south-facing window was blown in scattering glass across the kitchen. Fortunately, the residents were not in front of the glass as it shattered. Wall paneling was cracked at corners and a number of paneling nails were popped up.

About a mile farther north, along Sunset Road (3.9 km NNW), there was no clearly visible damage. We stopped at a 7-11 Store to make several phone calls; it had suffered no damage but its large windows were facing north, away from the blast direction. Continuing east through an undeveloped area there was no obvious damage until we reached the Boulder Highway (US-93). Along it, and traveling southeast, several businesses had broken windows. The new Cattle Baron's Casino (4 km ENE), under construction near the intersection with Pabco Road, had about 2/3 of its large second floor windows broken; they were 1/4" annealed glass. We stopped for lunch at McDonald's, where there were 16 undamaged 3'x4' windows, but one 7'x8' pane facing the blast was broken out.

The Henderson Chamber of Commerce, at the intersection of Boulder Highway and Lake Mead Drive, provided more copies of the Henderson map, but we noted an updated blueprint version on the wall that included Arroyo Grande Estates. A call to the engineer, Ben Sweet, was followed by a visit to his shop on Lake Mead Drive near Atlantic Avenue (3.8 km E). He gave us his single map copy to save us a week wait for a reproduction. He once worked for Holmes & Narver, DOE-NVO engineering consultants, and was most helpful. One west window in his office had blown in scattering glass across a drawing board, but there were no injuries. In that neighborhood every house had at least one window broken.

Driving west on Lake Mead Drive, we turned into the Hillcrest-Arthur-Albany neighborhood (2.9 km E), which was heavily damaged. There were many broken windows, broken doors, and bent garage doors. West of Albany Way, in the most westerly residential zone, there was a new commercial area of two large metal warehouse buildings (2.6 km E) where most windows were broken, all of the large overhead roller doors were blown from their tracks, and much insulation material was scattered from ceiling breaks. Across Lake Mead Drive to the north, commercial-industrial buildings suffered major damage with west-facing outer panels blown away, etc.

We talked our way through a road-block and proceeded west past the freeway crossing construction to another industrial building at the RR crossing (1.6 km E). It had sustained total wall panel damage on the west face. A disaster command post was set up at the Gibson Road intersection (570 m SE). There were about twenty TV teams, many fire trucks, military vehicles, etc, waiting for news or developments. The road was blocked to traffic headed further west along Route 146. On return to Henderson, we inspected a recent-model Oldsmobile sedan that had been abandoned beside the road; its windows were all broken and the roof caved in to the top of the seat level.

We then began a survey of residential damage along the southwest edge of Henderson. At Crest and Buchanan (3.2 km E) we talked with a woman resident who had six 30"x40" SS windows broken on west and north sides of her house, which faced west. There was also damage to doors which were blown open with failures at hinges and locks. Similar damage was noted to other houses in this neighborhood.

The next neighborhood visited was south of the RR with the western extremity along Tiger Lily Way (3.4 km ESE), where there were frequent signs of damage to windows and doors. Along Mountain View Road and south to Horizon Drive (4.4 km SE) window damage was scattered, about one pane per two houses. At Pacific and Horizon (4.8 km SE), a 7-11 Store had several large windows broken as it faced west. At the National Guard Armory (4.8 km SE) there was no damage visible from the outside, because the area was protected by a hill to the north. East on Horizon, window damage was noted as far east as Greenway Road (5.6 km ESE) and then south to Heather Drive (6 km SE). No damage was noted to the few residences southwest from the Greenway-Heather intersection. Traveling north on Greenway we noted window damage at Longacres Drive (5.4 km ESE) but not at the Black Mountain Country Club.

We were unable to see any damage to the Burkholder Junior High School (3.4-3.9 km ESE) or the Gordon McCaw School (4.7 km ESE), although newspapers had reported damage inside these. They have only a very few small windows, however. Throughout the area of Basic, Tungsten, Manganese and Atlantic (3.7-4.2 km E) and from Victory east to Water Street, it appeared that almost every house had at least one broken window even on sides facing away from the blast. Also, from Water Street east to Boulder Highway, and from Victory south to Basic Road, residential areas had frequent window damages. Along the length of Water Street (4.5 km E) and SE to Ocean Avenue, most of the store front windows were broken, particularly on the NE side of the street which was facing quarter-on to the blast.

Northeast of the St. Rose de Lima Hospital there was window damage noted along Aswell and Lowery Streets. Since damage density appeared light along Boulder Highway, and it was getting late, we elected to skip any survey of residential areas NE of the Highway. I later learned from N. Finley (SNLA-6321) that there were windows broken for at least another mile NE along Lake Mead Drive East (6 km ENE).

A residential area NE of Boulder Highway, from Pabco to Sunset Road (3.9-4.4 km NE), had scattered window breakage, probably averaging less than one broken pane per house. We were generally unable to see more than one or two sides per house in such older residential areas because of plantings and crowding, however, so their damage was likely to be double what was visible from the street. Our return to the El Morocco Hotel was via DI Road (12.4 km NNE), where we noted a few broken store windows which we intended to check in more detail on Friday.

Friday, May 6, 1988

Our first order of business was to visit the URS/J. A. Blume office, contacting J. L. Woodruff and D. E. Calfee. They provided copies of seismograms from LVW (NW LSV along Charleston) and SE-6 (UNLV Campus), which showed a 4-minute separation between first and second ground motion packets, with the largest acceleration amplitudes (by a factor of at least 2) occurring about 1/2 minute into the second packet. These recordings also showed ground motion responses to the airblast waves which may eventually be interpreted as overpressure values. They were unable to make a surface burst yield estimate from the 3.5 magnitude Richter scale value reported by the press.

Woodruff lives west of Flamingo Road and Boulder Highway (9 km NNE) and said about every third home in his neighborhood had at least one broken window. They also had a list of reports from their various seismic event contacts, that showed which large hotels and other high-rise buildings had been damaged.

We next returned to the National Weather Service airport station (12.9 km WNW) to pick up further weather data before we split the team to allow Vann to check into damage reports from the Hilton Hotel and injury data from hospitals. We first drove along Sahara Avenue, where R. C. Bass (SNLA-7111) had experienced this incident during lunch. One vacant store near Eastern Avenue (13.8 km NNE) had three broken windows which had previously been punctured by BB shots, but another with two BB holes was not broken.

At Bertha's, a home furnishings boutique east of Maryland Parkway (15 km NW), two of four huge 79"x139" plates of 1/4" annealed glass were broken. Nearby in Christensen's Jewelry, one of six 90"x98" plates was broken. All these store windows faced south. In a barber shop with a broken window we got a first-hand description of the event, where again the first blast wave got everyone's attention, so that they were not near the window when the largest amplitude wave struck. A piece of falling glass put a large dent in their antique brass spittoon. In a nearby luggage shop several large pieces of broken glass were noted stacked inside (the shop was closed) that were 1 to 2 ft^2 in area.

On St. Louis Avenue, west of Maryland, Trinity Temple had one large pane broken out facing north and away from the blast. We did not explore any further to the north. Traveling south on Maryland and in the first block south of DI Road, a shopping center on the west side of the street (13.8 km NW) had several broken store front windows. One store had two of its 76"x104"x1/4" annealed plate windows broken. One had cut an employee as it blew in; she had "several" stitches in her head. Curiously, another of their windows broke on Thursday during the strong windstorm, but it was tempered glass which shattered into small pebbles. The shopping center manager also showed us a store front pushed in about three inches in a southeast-facing interior corner location, but these windows did not break. Ceilings throughout this area showed various stress patterns. Another store had one of four 85"x109" panes broken.

We had arranged to meet Vann at 1300 PDT at Eastern & Flamingo Road, (11.7 km NW) for lunch, which we had at Friday's near Maryland. They had sustained no visible blast damage. Just north of the Eastern and Flamingo intersection, an Ethan Allen furniture store had one pane broken on the south side.

Following lunch we visited the Boulder Highway - DI Road area. South of DI Road, around Sandhill Road (11.3 km NNW), there were occasional clusters of homes with single broken windows. Northeast of Boulder Highway (11.3 km N) we spoke with a window repairman who maintained that nearly every home in that area had at least one broken window. He had a ten-day backlog of orders from that neighborhood, and claimed to be working day and night. In an area north of Vegas Valley Drive and near Nellis Boulevard (11.9 km N), we found no indications of damage, but it contained mostly apartment houses with relatively few small windows and mobile home parks.

At Sam's Town, on Boulder Highway at Nellis Blvd., there was no visible damage, although an occasional window was out along Boulder Highway south to Tropicana Road (7.9 km N). Only two or three total store windows were seen to be broken along Tropicana Road (9 km NW) during our drive to the airport, where the TTU pair had a 1730 PDT flight home.

General Remarks

Being the most familiar with Las Vegas, I was elected to drive on these surveys. Consequently, my notes are incomplete in many instances. Both Vann and McDonald took at least twice as many photos as I did, and they will be available to me later. Also they both had tape recorders and made extensive oral reports which will eventually be transcribed and copied.

My early conclusion about the 1-kt NE explosion yield estimate still appears reasonable. From the damage intensity at Arroyo Grande Estates, which I judge to be a bit worse than was sustained at the MISTY PICTURE Admin Park (from 0.4 psi overpressure), yet possibly not quite so severe as I recalled seeing at the Civil Defense housing structures following Operation TEAPOT nuclear test Turk (at 0.5 psi overpressure), I would still estimate the overpressure near 0.5 psi. This overpressure would be expected near 2.1 km from a Standard 1-kt nuclear explosion, free-air burst. Since the Arroyo Grande Country Club building was about 6000 feet from the PEPCON plant, it may be concluded that the strongest explosion was close to a 1-kt NE air-burst equivalent. This could be duplicated with a 250-ton TNT surface burst.

Recent discussions (prior to the accident) with Hercules, Inc. (Magna, UT) and Salt Lake County Planning Department officials, regarding a proposed new missile motor casting facility, were based on a 10% TNT equivalence for detonating rocket motor fuel. The military position has been that this material is not detonable. An accident at a Titan motor plant, however, gave damage that was interpreted to give a 10% TNT equivalence, so that figure is being used in defining safe separation criteria for a new Hercules plant. This would indicate 5-million pounds of AP as the source of the largest Henderson blast, plus possibly that much more for the three moderate and many, many very small explosions that have been reported. When first contacted on May 7, 1988, G. M. Daurelle, of Hercules, offered 2- to 5-million pounds as a likely amount that would be stored at the PEPCON facility. Later, on May 13, he had gathered further information that from 10- to 50-million pounds could have been involved.

N. Finley (SNLA-6321) and A. Dudley (Spectra Research Inst.), obtained an 8.5-million pound figure last week from a Nevada OSHA representative. Thermodynamic yield equivalence, calculated by P. W. Cooper (SNLA-7132), is 70%, which might be used to infer as little as 1.5-million pounds of AP in the total incident. The widest uncertainties at present are thus in the TNT airblast equivalence and the quantity of available fuel. When I proposed (April 21, 1988) a scale model experiment to establish this explosive potential for the Hercules facility, I was told that it would take a 50% by weight booster to detonate this rocket motor fuel and thus a simulation test would not be pertinent. Now I am not so sure.

I have both newspapers, the *Las Vegas Review/Journal* and the *Las Vegas Sun,* for four days, May 4 through May 7, 1988, which I have stripped down to include only reports on this incident. Also, I took one 36-shot and half a 24-shot roll of color slides of damages.

APPENDIX B. EXCERPTS FROM NEWSPAPERS REGARDING THE HENDERSON, NEVADA, EXPLOSION ON MAY 4, 1988

(Directions and distances added in parentheses as available.)

Las Vegas Review-Journal, May 4, 1988, Extra

Page 1A Lead: Estimated 10 dead, 200 injured, by multiple separate explosions at Pacific Engineering Company (PEPCON) ammonium-perchlorate (AP) plant near Henderson, NV (HEN). Fire began with machinery malfunction. HEN fire captain was called and was en route after first explosion; second explosion blew out his windshield. He saw the blast approaching across the desert. Kidd & Co. marshmallow plant (400 m WNW) next door to PEPCON was also destroyed, causing marshmallow rain. St. Rose de Lima Hospital (SRLH) (4.6 km E) estimated 75% of injuries were caused by flying glass. Hospital sustained broken windows and a door frame was knocked off. Southern Nevada Vocational-Technical Center (6 km NNW) had damage to nearly all of its windows.

P 4A: 7-11 Store on Pacific Ave. (4.8 km SE) had 3 windows blown out by the second blast. Clerk smelled gas and left. At home, she found windows blown out at 626 Greenway Road (5.6 km ESE), 10 miles distant. OK Tire Store on Lake Mead Drive had all windows in store and some in cars broken out. Some Thrifty Store windows broken out; part of its ceiling caved in.

Las Vegas Sun, May 4, 1988, Extra

P 1A, *Four...*: Four explosions were set off by a fire started in the PEPCON "Batch House" where rocket fuel is mixed. A mushroom cloud climbed to 300 feet after the first explosion. High wind pushed the fire around. 750 tons of ammonium-perchlorate (AP) will burn in two minutes. HEN Sanitation Treatment plant (5.2 km ESE) had all its windows shattered. Second story windows were broken in house in Desert Springs (subdivision?).

P 1A, *Those...*: PEPCON worker reached his truck in parking lot after fire alarm for evacuation following first blast, and drove through the desert; the next explosion rocked truck and broke windows. At 1000 yards, near Kerr-McGee plant entrance (4.7 km E), blast threw a Ford Bronco from center lane onto the median. At Chemstar, Inc., at 0.5 mile range (1.6 km E), an employee said it "propelled him off his feet"; he suffered a broken wrist. Other Chemstar workers were blown 15 feet off ground and slammed into a wall; one was knocked unconscious.

P 3A: One Burkholder Middle School (3.4-3.9 km ESE) student was hospitalized after a ceiling beam fell on her head from first blast. At least one windshield was shattered in the school parking lot. At Laura Deering School the roof started to come down, but damage was mostly cosmetic.

P 4A: A steelworker on Sunset Ridge bridge (2.2 km E), 0.5 mile from blast, was blown from his perch while working on cables; he fell 20 feet to ground, sustaining a broken ankle. Cars were seen driving confusedly around HEN with broken windshields. At Henderson Barber Shop, operator heard three explosions and received cuts on his arm and neck from flying glass. A tourist on Highway 146 (Lake Mead Drive-West) (>460 m S) claimed blast "almost destroyed our car".

Las Vegas Sun, May 5, 1988

P 1A, Lead: Four explosions occurred. Curfew set in HEN from 8 pm to 6 am. At Glen Halla Health Care, 1.25 miles from blasts, glass was flying and residents were evacuated to Las Vegas.

P 1A, *Victims...*: D. Scroggins, lab technician, felt four explosions. Sassy Scissors on Water St. (4.4 km E) was one of few stores with no broken windows. Gateway Apts. at 1100 North Center (6 km ENE), had windows broken out.

P 1A, *Councilman...*: HEN City Manager Gary Bloomquist was at Green Valley Athletic Club when 2nd blast literally floored him. The first had blown double glass doors open. His City Hall office has been boarded up. Councilman Michael Harris got to Tropicana when the big one hit, moving his car. At his home, windows were shattered and a back door was blown off it hinges.

P 12A, *UMC...*: An ironworker first saw cloud of smoke, then the first blast "blew me off the bridge" (see previous excerpt). Barber Helmke heard three blasts. Tourist on Highway 146 in Chevrolet Corsica had passenger side windows blown out, windshield cracked, and dents pounded in roof and trunk.

P 12A, *Blast...*: A Burkholder School student fell off stairs. The radio repeater on Black Mountain (12 km S) was knocked out by blast.

P 14A, *Hospital ...*: Patients at SRLH received minor cuts. Part of the hospital roof caved in. Emergency power was necessary. Two patients were received in critical condition and airlifted to Valley Hospital, Las Vegas.

Las Vegas Review-Journal, May 5, 1988

P 1A, Lead: "Three thunderous explosions...". About 100 workers were at PEPCON and Kidd & Co. plants; Kidd is the second largest marshmallow maker in the U.S. Workers fled into the surrounding foothills, and they were there when the first explosion hit...shortly thereafter the second explosion occurred. The second blast caused most of the damage. Cal Tech recorded 3.5 Richter scale on its earthquake recorder. "A successive series of smaller explosions followed the three major explosions, which were spaced just seconds apart." Flames shot 100 feet into the air. One expert in chemical engineering at the University of Nevada - Las Vegas, said the force was "equivalent to several tons of pure high explosive." There were 114 casualties. PEPCON President Gibson was driving to the plant when the first blast shattered his windshield, crushed the top and punched in the trunk. After the explosions flattened the PEPCON plant, Gibson and Suvoski re-entered the compound to turn off the ammonia pipeline. Everyone was trying to get out...cars were leaving (250-270 m N) when one explosion blew out windows. Others described how they tried to drive away...when the first explosion hit. The force...blew the workers out of their cars.

P 1A, *Damage...*: Virtually every store window along Water St. was shattered. "The first two blasts were ungodly, the others...were not quite so bad." At the NAPA Auto Parts Store, blast sounded like a sonic boom. Barber Mike Brooks said "first explosion rocked his shop; the second took out window, frame, and everything." HEN city bought 1000 pieces of plywood to help store owners board up their broken windows.

P 19A, *Homes...*: In Green Valley, at 2 miles range, the second blast blew Rich McSimov through his front door. At 1800 Nuevo Road (3.1 km NW) nearly every window was blown out. House had abundant cracks, front doors on ground, etc. Up and down Nuevo Road, "frames surrounding doors and windows were ripped from the walls."

P 19A, *Cloud...*: The explosion cloud remained at least 1000 feet above ground as it passed over Glendale (50 miles northeast).

P 19A, *Gamblers...*: In Sam's Town Casino, at 6 miles range (8.9 km NNW), black dust billowed from the ceiling. Security began evacuation when the second of three blasts occurred. At the closer Nevada Palace Casino, there was "much more severe damage", with windows broken in at least 39 rooms; the casino was closed for two hours.

P 20A: A PEPCON worker ran to his truck in their parking lot just before the first explosion, then drove a mile across the desert (1.8 km N) when a second blast hit. The driver's side window was broken, but he kept driving and detoured down Sunset Road.

P 1B: Small fires had occurred infrequently at the plant and workers were instructed in fighting them. This one spread too fast. One worker said "The first of four blasts followed moments later and took my hard hat right off. The big (second) one threw me 15 feet."

P 1B, *Las Vegas...*: A student in class at UNLV, Humanities Building, (12.2-13.5 km NW) heard "a big bang followed by falling glass." At Nellis AFB, more than 10 miles away (22 km N) the blast shook buildings.

Las Vegas Sun, May 6, 1988

P 1A, Lead: PEPCON Vice President & Operations Manager, B.B. Halker died in blast; Comptroller R.W. Westerfield is missing.

P 1A, H. Greenspun, Editor: "Windows shattered as far away as downtown Las Vegas (18 km NW)."

P 10A, Zenoff, Columnist: One woman reported "...all her picture windows overlooking Black Mountain Golf & Country Club (>5.3 km ESE) were blown out."

P 2B, *Evacuation...*: An evacuation alarm seven to ten minutes before the explosion made it possible for all but one of the 74 PEPCON workers and the 30 marshmallow factory workers to escape. There was near panic with thousands trapped in their cars on the Expressway as the toxic cloud passed overhead.

P 2B, *Victim...*: "About every window" was broken at 221 Carson Way (3 km E), HEN. They first thought blast was a sonic boom but children called them to see the smoke; when the second blast hit they ran inside as the third blast blew in all the glass.

P 2B, *First lawsuit...*: A casino patron broke an arm and sustained numerous cuts as she was thrown to the floor.

P 2B: At Southern Nevada Hospital, 3 were still hospitalized. One, Pat Rose, is in critical condition. He was driving to Lake Mead (>3.8 km ENE) when the first blast threw a rock through an open car window and caused a skull fracture. A friend pulled him into a culvert until the explosions had stopped. Also, 1-day old Rebekah Wittig had her left eyelid pierced by breaking glass at SRLH (4.6 km E).

P 3B, *Insurance...*: Farmer's Insurance Company received 900 claims. Allstate received over 800 claims. Most were for broken windows and doors.

P 3B, *Stunned...*: When a second, large explosion ripped PEPCON apart, the marshmallow factory workers began running too.

P 3B, *Schools...*: Over $1 million damage to HEN schools. Basic High School had front entrance buckled and sunk several feet.

P 8B, *Explosion...*: Virtually all of the 22,000 homes within a three-mile radius of the blast suffered structural damage of about $5000 each. $100-million total damages according to HEN Senior Inspector. Roof damaged at Fire Station #2. More costly damage to 24 houses on Bismark Street (2.9 km E).

M. Stevens, LVRJ editor, was in an office at Maryland Parkway & Flamingo Rd. (12.8 km NW) when the first explosion rocked the building. There was a thickish yellow plume cloud. They ran outdoors. The second blast added a billow of black smoke.

Las Vegas Review-Journal, May 6, 1988

P 1A, *Fire...*: "The burning AP drum looked like a Roman candle." One worker had seen and put out a dozen previous fires. AP burns at 800°F. A Kidd worker said "intercom warned to leave the building by back door. I bent to pick up my purse and the roof was lifted off the building." C. Cox said "the ground was rippling as I was running." "A succession of ear-shattering explosions worsened their tortured journey." The first blast flattened cars and tore through the chemical and marshmallow plants. C. Bainbridge & R. Christensen saw smoke, ran toward plant gate, "outran the grit-filled cloud...looked like a tidal wave of dirt coming toward us," reached Bainbridge's truck and headed down Gibson Rd. "Three guys jumped in back, going 30 mph when the second explosion hit. The truck just stopped cold."

P 1A, *Shuttle...*: Blast knocked out half of the nation's capacity for producing AP.

P 14A: Forty-two damage assessors, divided into teams, began surveying on Thursday.

P 14A, *Insurance...*: State Farm received over 1600 claims, averaging $1000 each; they expect a total of around 5000. Windows were broken 15 miles away from the blast. Allstate spokesman said 800 claims were received; another worker said 1000.

P 15A, *Call...*: One woman telephoned less than a minute after the first call (from Westerfield) about "an explosion across from the ice rink on Sunset Road." A third call came seconds later "They've had two explosions...I'm up on the mountain and I can see it's spreading quickly."

P 16A: Small fires were common at the PEPCON plant. Liquefied ammonia and hydrochloric acid are mixed together to create ammonium chloride. The chemical is the same atmospheric irritant...known as the "Henderson Cloud". Ammonium chloride in a water solution is then run into a tank with sodium perchlorate, a salt, and then electrified. The process creates precipitates of salt and ammonium perchlorate, the rocket fuel oxidizer, in liquid form...then dried into a solid. At Kerr-McGee plant, a different process is used but its description is a trade secret.

P 18A: Emergency workers had trouble hearing their radios because of the noise created by helicopters.

P 19A: Kidd Assistant Plant Manager Wally Cox was thrown to ground three times while fleeing the fire (>600 m NW) and suffered a perforated eardrum.

P 20A: The AP batch drying machine snagged gears, which sparked a small fire in the electrical insulation that leapt to a nearby 55-gal drum of AP. This flashed to a much larger fire. At this point workers began to fear a massive explosion. Also then...someone...called the Henderson Fire Department. Electrolysis processing created a large amount of hydrogen and workers believe that it fueled the second explosion. Several later explosions were believed to have been more barrels of AP. 306 persons were treated by hospitals.

P 10B: "Some estimates equated...one-kiloton nuclear explosion..."

P 1B, *Miracle...*: Dozens of vehicles were demolished at both sites (PEPCON & Kidd). A railroad car was blown off its track. "Plant workers were thankful that the explosions were vertical and not horizontal."

P 1B, *HEN Cleans...*: There was broken glass and ceiling tiles at the Sunset Sandwich Shop. Safeway on Boulder Highway had windows broken out. Barbara's Boutique in downtown HEN had some broken windows. This-is-the-Place Bookstore had its ceiling buckled. In a furniture store displays were gouged and ruined by flying glass. Glass had to be cleaned from shelves at Video Tyme, on Boulder Hiway. The Cattle Baron's Casino (4 km ENE) had $100,000 damage. SLRH (4.6 km E) had 80% of its outside windows broken. On Vallante Drive (3.1 km NW), nearly every $130,000 home was damaged. All four outside walls of the Keyes home had gigantic cracks; the foundation appeared lopsided. McCabe's bedroom window was blasted from its frame, with glass falling all about.

P 1B, *Schools...*: The front door was blown off at McDoniel School (4.2 km NW) The first blast knocked all the ceiling tiles down on the students. They evacuated before the second big blast hit. The Burkholder School (3.4-3.9 km E) principal said "with all the glass...a miracle no one was hurt more seriously."

P 2B, *Glass sales brisk...*: Black Mountain Glass & Mirror Co. had to repair its own windows as well as its customer's. Garage door companies were scrabbling; most garage doors were damaged beyond repair.

Las Vegas Review-Journal, May 7, 1988

P 1A, Lead: The PEPCON plant will not be rebuilt in the valley. At least 350 people were injured; damages were over $81 million. AP combined with hydrogen gas ... set off at least three massive explosions. Comptroller Westerfield, partially crippled by polio, was unable to get far enough away. Only two persons remained hospitalized on Friday. One, Pat Rose, was still unconscious. Some patients also suffered respiratory problems, ruptured eardrums, and sprained limbs.

P 1A, *Reaction...*: PEPCON is located in an unincorporated part of Clarke County, under jurisdiction of county commissioners. John Sloan, Green Valley resident: "They got three other larger industrial plants out there that could make Wednesday's explosion look like a firecracker."

P 11A: A propane plant, under construction next door to PEPCON, had built two 30,000 gallon tanks but they were not yet filled. They were the least damaged of the facility.

P 1A, *County...*: There are no federal, OSHA, or state standards for handling AP.

Las Vegas Sun, May 7, 1988

P 6A: The Cattle Baron's Casino suffered $500,000 damage from the blast.

P 6A, *Bryan...*: The Kerr-McGee plant has a much smaller AP production than PEPCON.

P 1B, *School...*: Basic High School (6.5 km E) had extensive structural damage to its main entrance and inside ... some ceiling tiles dropped and 3-4 thousand square feet (of 230 kft^2) of ceiling dropped.

P 1B, *Sunspots,* by R.McIlvaine: "They tell us the force of the blasts was about 1% of the smallest of our atomic bombs." Passengers on Air West at 2000 ft over ground heard and felt the explosion.

P 2B: Westerfield called fire department at 11:51 "We just had a big explosion and everything's on fire." Fire department: "There was suspicion that the first fire at the plant could have started 15 to 30 minutes before that time." "Sirens could be heard in the background as Westerfield is speaking." Westerfield worked in the administrative offices.

P 1F, Weekend *Real Estate* Section: At Arroyo Grande, a manufactured housing community, lots are $25-$33,000. Eventually it will have over 360 homes; minimum age for residents is 40 years; the clubhouse has 4000 ft^2; dues are $25 per month.

Albuquerque Journal, May 13, 1988

P A3: PEPCON President Gibson claims that a high pressure gas line had been leaking for 30 minutes before the fire.

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7137	R. D. Statler
7137	J. R. Dickinson
7137-1	R. D. Pace
7170	R. D. Bentley (10)
7533	F. H. Mathews
7535	D. C. Bickel
8524	J. A. Wackerly
9111	H. B. Durham

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